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TACTICAL PERFORMANCE CHARACTERIZATION APPLIED TO STUDENT PILOTS

By

Michael J. Walsh
George H. Burgin
Lawrence J. Fogel
Decision Science, Inc.
4901 Morena Boulevard
San Diego, California 92117

OPERATIONS TRAINING DIVISION
Williams Air Force Base, Arizona 85224

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MARTY R. ROCKWAY, Technical Director
Operations Training Division

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The purpose of this effort was to develop new methods for characterizing important features of pilot tactical performance for display at the instructor/operator stations of flight simulators. In particular, the work involved developing a technique for computing the weight (importance) a pilot assigns various performance criteria. Phase I involved developing the techniques and methods to be used. An AML pseudopilot with fixed weights was utilized as the pilot to be "modeled." A modified AML program using observations of the actions of the pseudopilot without access to the weights of the pseudopilot calculated the weights used by the pseudopilot. Phase II involved the application of the method to human pilot data collected on the Simulator for Air-to-Air Combat at Luke AFB.

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The AML program determines its next action by evaluating several alternative next moves against the projected trajectory of the opponent. A set of importance weighted questions concerning performance criteria with responses involving yes or no answers are applied to possible alternative actions. Each alternative is given a score equal to the sum of the weights of those questions with affirmative answers. That alternative with the highest score is taken as the next maneuver. In observing the pseudopilot (AML program), since the chosen maneuver must have the highest score, the sum of the weights associated with it must equal or exceed the sum of the weights associated with other possible actions. This gives rise to a set of inequalities involving the weights which can be solved by Linear Programming technqiues. Application of this technique in Phase I gave reasonably accurate results.

Analysis in Phase I indicated that for Phase II the performance criteria should be combat-maneuver specific. The selected maneuver was the high-speed yo-yo. Data from several high-speed yo-yo maneuvers flown by instructor pilots on the SAAC were obtained, and the best flights were used as reference high-speed yo-yo maneuvers. The reference yo-yo maneuvers were used for subsequent flights by student pilots in determining the truth values of the questions involving the performance criteria.

Critical problems with the technique were discovered when used to determine weights associated with human student pilot actions. For those instances with all nonzero weights, a unique solution could not be found so that zero weights had to be allowed. This resulted in determined weights being either zero or five (maximum weight allowed) with no correlation between the weights and flight performance.

In summary, a method showing initial promise failed when used on human student pilot data; this because of the inherent inconsistency and lack of repeatability in human student pilot actions.

ACKNOWLEDGEMENT

This is to express our appreciation for the personnel at Luke Air Force Base through whose cooperation we were able to obtain flight data from the SAAC simulator. In particular, we are indebted to Bob Coward for arranging the data collection, to Bill Hopkins for the necessary programming to record the required data, and to the instructor pilots and the student pilots for performing the desired maneuvers.

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I. INTRODUCTION

Flight simulators are of critical importance in the training of combat pilots. In this regard, data displayed to the instructor/operator of the flight simulator should characterize the performance succinctly to facilitate the instructor's tasks. These include measuring the proficiency demonstrated and producing a medium for superior instruction. The purpose of this effort was to develop specific techniques that are suitable for the analysis and characterization of tactical performance in a flight simulator.

The techniques are based on the use of the adaptive maneuver logic (AML) (Reference 1), a computer program developed to act as a real-time, interactive opponent on flight simulators. The AML program decides its moves on a second-by-second basis by examining its relation to its opponent. At each decision point, the program projects its own position three seconds into the future, based on executing each of several hypothetical, alternative moves. It also projects its opponent's position and then computes the answers to a number of yes or no questions (e.g., "Will I be above my opponent?", "Will I be behind my opponent?"). Each question is weighted by a number that reflects its approximate value in combat flying. For each move, the program adds up the weights of the questions answered "yes." It chooses the move with the highest sum as the next move to make.

The weights applied to each question determine the quality of flight by the AML. One important aspect of skilled performance is having the correct internal representation of the relative importance or weights for questions such as these. With a capability of inferring these weights from recorded or incoming flight data, novel information could be displayed to the instructor about what the pilot is emphasizing and trying to achieve when performing combat tactics. The approach here was to develop such a capability by using a modified AML program Specifically, this AML was expected to compute the set of weights that allowed it to most closely model the pilot's performance. It was theorized that these weights, or at least the relative values, would approximate those of the pilot.

In Phase I (Reference 2) of this effort, basic computing techniques were developed using data generated

by one AML flying against another. Given a record of performance on a second-by-second basis of the AML, a set of weights was computed by a modified AML program which, if used by the first AML, would cause it to duplicate the observed flight. Phase II concerned the use of these techniques for the purpose of modelling the flight performance behavior exhibited by human pilots.

Part of the Phase I work included a reexamination of the questions used by AML to assure that they would provide meaningful data to an instructor. It was decided that the questions needed to be revised to reflect information on how well the pilot performs the maneuver in question. A further decision was to restrict attention to a single maneuver -- the high-speed yo-yo. Work in Phase II concentrated on implementing the new set of questions, obtaining good reference flights from instructor pilots, getting the AML to fly a good high-speed yo-yo, collecting student data, and using AML to compute weights (or importances) for the questions for each student.

Although initially the method showed promise, success failed to materialize because of a lack of repeatability in human student pilot actions.

II. DISCUSSION

The question was raised whether the AML with its relative geometry criteria could simulate the pilot flying different standard air combat maneuvers. It was, therefore, proposed that for Phase II the flights be restricted to a single maneuver but not a simple one. The one chosen was a high-speed yo-yo against a noninteractive target flying a defensive turn. For a given initial condition and noninteractive target, a good reference high-speed yo-yo should be developed, and the criteria in the question set should involve this reference yo-yo. This should provide meaningful data to the instructor and force the modified AML to fly a high-speed yo-yo approximating the reference yo-yo. Finally, the adequacy of the set of trial maneuvers was reexamined and the necessary data collected at Luke AFB. These activities are described next.

Question Set

In determining an adequate question set, two points had to be considered, First, the information contained in the questions should be adequate for the short-term maneuver logic of the AML which requires relative geometry and dynamics information for the AML plane. On the other hand, since the AML is to be used as a basis for measuring the flight performance behavior of human pilots, the questions must be meaningful to a pilot. They should contain variables directly displayed to the pilot or relatively easily perceived by the pilot. On the basis of these criteria, the following set of eight questions was developed:

1. Is my relative altitude correct?
2. Is my relative altitude rate correct?
3. Is my relative velocity correct?
4. Is my load factor correct?
5. Is my range correct?
6. Is my range rate correct?
7. Is my line-of-sight angle (LOS) correct?

8. Is my throttle setting correct?

The criteria for correct values were to be taken from the reference yo-yo maneuvers. In getting the AML to fly a high-speed yo-yo, the following procedure was used. For each question, the absolute value of the difference between actual and reference values was calculated and normalized by the maximum error in that question. This was then multiplied by a weight factor which remained constant during the entire maneuver. The total value V for a given trial maneuver was then:

$$V = 100 - \sum_{i=1}^{8} \left| \frac{\text{REFERENCE VALUE}_i - \text{ACTUAL VALUE}_i}{\text{MAX ERROR}_i} \right| W_i$$

where W_i was the weight factor associated with the ith question. At each decision point, a value V was then determined for each trial maneuver, and the trial maneuver with the highest value V was chosen as the next maneuver for the AML.

Trial Maneuvers

We also had to consider the question, "What is a good set of trial maneuvers for a high-speed yo-yo?" The original set of trial maneuvers in the AML consisted of a continuation of the present flight, a straight flight or maximum-g turns in the two planes (maneuver planes) that form plus or minus the tilt angle (an input parameter) with the base plane (the plane defined by the AML airplane's velocity vector and the opponent's extrapolated position). It was decided to add four more trial maneuvers to this set. These were four maximum-g turns in the planes which form plus or minus twice and three times the tilt angle with the base plane. Also, since the tilt angle is an input parameter to the AML, the value of it could be changed between runs, thus, obtaining different sets of trial maneuvers, if desired.

For the original AML, the base plane defined by the AML airplane's velocity vector and the opponent's extrapolated position gave trial maneuvers which allowed the AML considerable success in getting in a cone behind the opponent. While this position is the goal of the attacker in a high-speed yo-yo after the apex, it is not so for that part of the flight prior to the apex. Further, since the purpose here is basically to fly a

yo-yo close to the reference yo-yo, it was decided that a better base plane would be the plane defined by the AML airplane's velocity vector and the projected position of the reference yo-yo.

Reference Yo-Yo

Finally, a set of reference data for good high-speed yo-yo maneuvers had to be obtained. Collection of these data was accomplished at Luke AFB on the Simulator for Air-to-Air Combat (SAAC) simulator. Initially, 12 different initial conditions (I/Cs) were considered. After some trial runs and discussions with the instructor pilots at Luke AFB it was decided to have only two different I/Cs and have each of the two instructor pilots fly three runs for each I/C. These I/Cs were chosen so that immediate execution of a high-speed yo-yo would be indicated. The I/Cs were angle-off's of 50 degrees and 60 degrees to the target aircraft, 550 KIAS velocity, range of 8,000 feet, and altitude of 15,000 feet. The target aircraft had velocity of 375 KIAS, altitude of 15,000 feet, and was to fly a 3g defensive turn.

The flightpath data, recorded in 32-bit words in Sigma 5 format, were then converted to 48-bit words compatible with the AML program on the CDC 3600 computer and stored on magnetic tape. The data were checked for the number of files (i.e., the number of flights) and within each file or flight the number of blocks of data. A block of data was recorded every half-second during the flight. This file information was maintained so that any given segment of flight data could be read from the magnetic tape.

Using plot routines, the following functions of time in the flight were plotted for each yo-yo: (a) line-of-sight (LOS) angle, (b) range and range rate, (c) mach number, (d) altitude, and (e) ground trace. Since one of the team members is a former fighter pilot, it was decided to have him rate the different yo-yo maneuvers on the basis of these plots. For rating purposes, the maneuver was considered completed when the 3,000-foot range point was reached.

Criteria used in rating the runs included minimum undershoot/overshoot, maximum altitude difference at the apex, range rate decreasing up to the point of maximum altitude difference and then increasing until the 3,000-foot "in-range" point, minimum range rate at the apex and LOS angle approaching 0 at 3,000-foot range. Each flight

was scored on each plot as well as on the elapsed time to completion. The scores for each flight were summed and the flights ranked by total score.

Run #14 was rated the best for the first instructor pilot and run #22 for the second, with run #14 rated best overall. These two runs were used as reference runs. Figures 1 and 2 are the altitude and ground trace plots for run #14, and Figures 3 and 4 are for run #22.

Normal Acceleration

In the Phase I part of this study, it was discovered that the recorded acceleration along the body z-axis, a_z, was not always in agreement with that computed by the AML using recorded flightpath data. Since load factor (i.e, acceleration along body z-axis plus component of gravity vector along it) is a required input to the AML program, it is essential that the load factors agree. Two listings of aircraft simulation programs were looked over. In both, the accelerations were computed in the body axis coordinates rather than in inertial coordinates as in the AML. The results should be the same, but it was decided to compute them in the body axis as a check.

Now the acceleration, a_z, along the z-axis in body axes coordinates is given by

$$a_z = \frac{dW}{dt} + PV - QU$$

where U, V, and W are the velocity components along the x, y, and z body axes, and P and Q are the roll and pitch rates. a_z was computed by this formula at various points in the flightpaths for both the attacker and target aircraft. The computed results for the target agreed well with the recorded a_z over all parts of the flightpath, but the computed results did not agree with the recorded a_z throughout the entire flightpath of the attacker. During the portion of the flight were the attacker is climbing and turning rapidly, the recorded a_z is much larger than the computed load factor; for example, at 10 seconds the recorded a_z is 6g while the computed load factor is 4.19g. In order to have compatible load factors, it was decided to compute them from the recorded

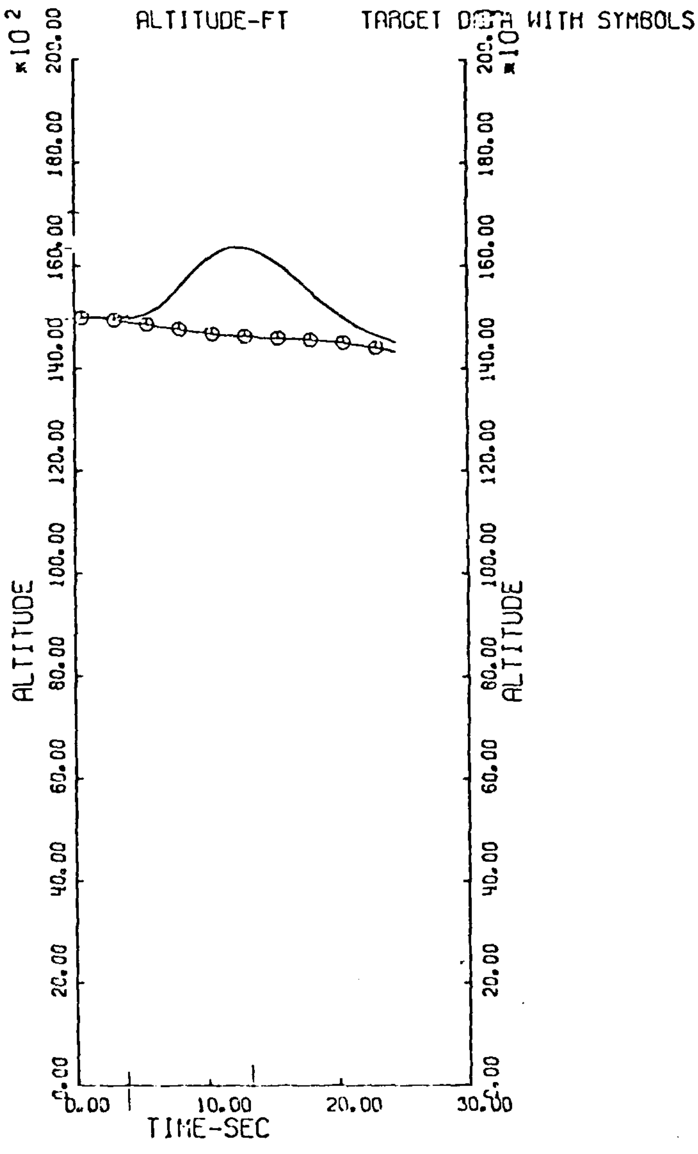

Figure 1. Altitude plot for reference flight #14.

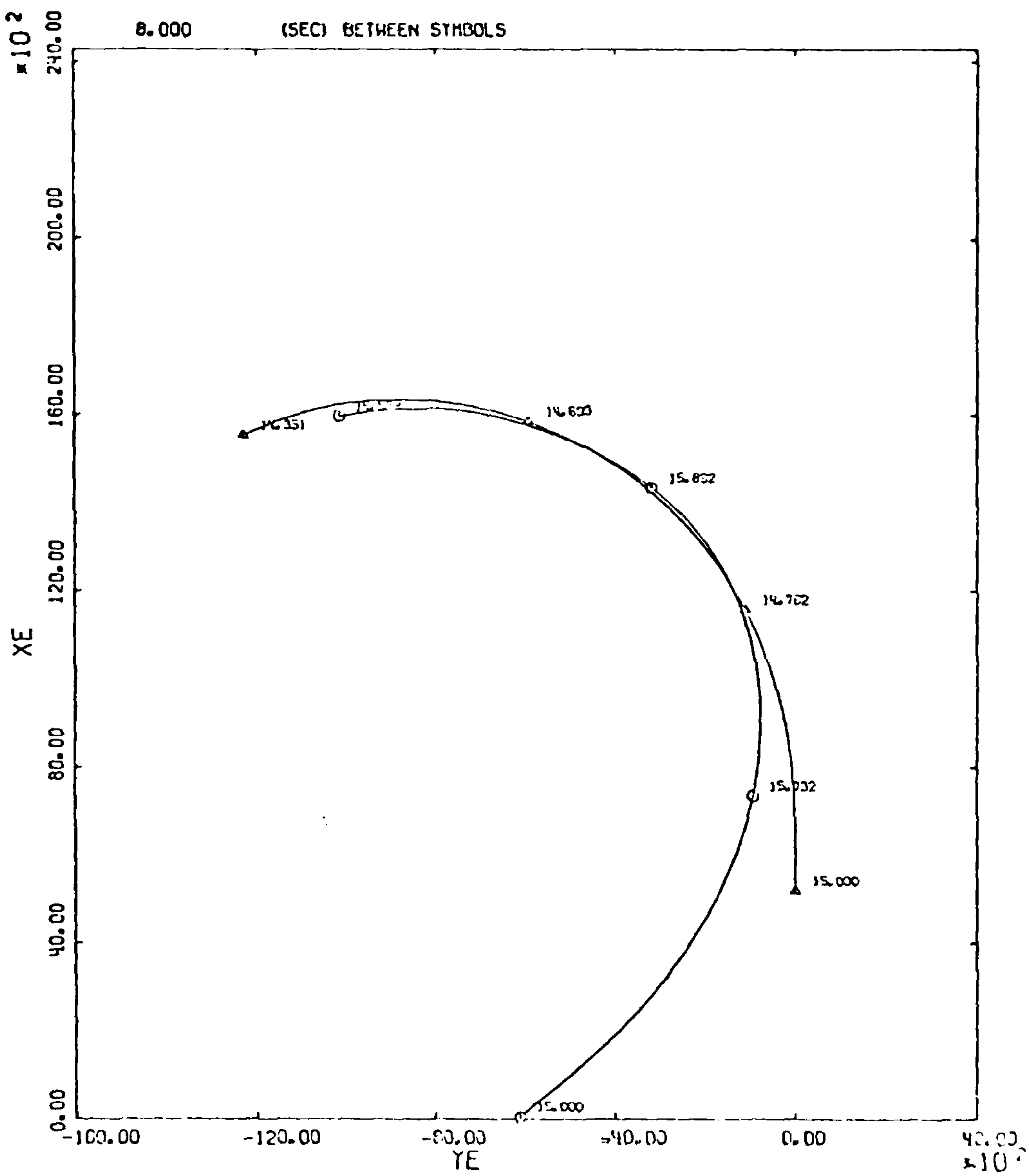

Figure 2. Ground trace for reference flight #14.

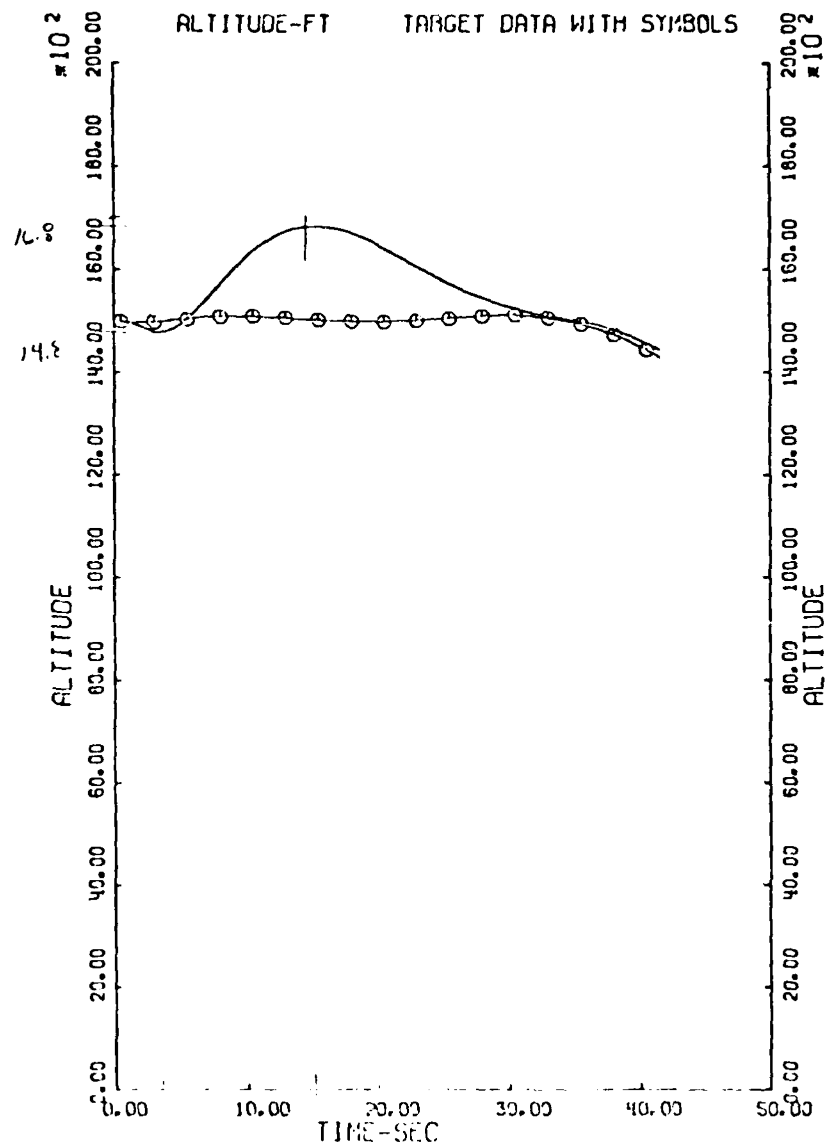

Figure 3. Altitude plot for reference flight #22.

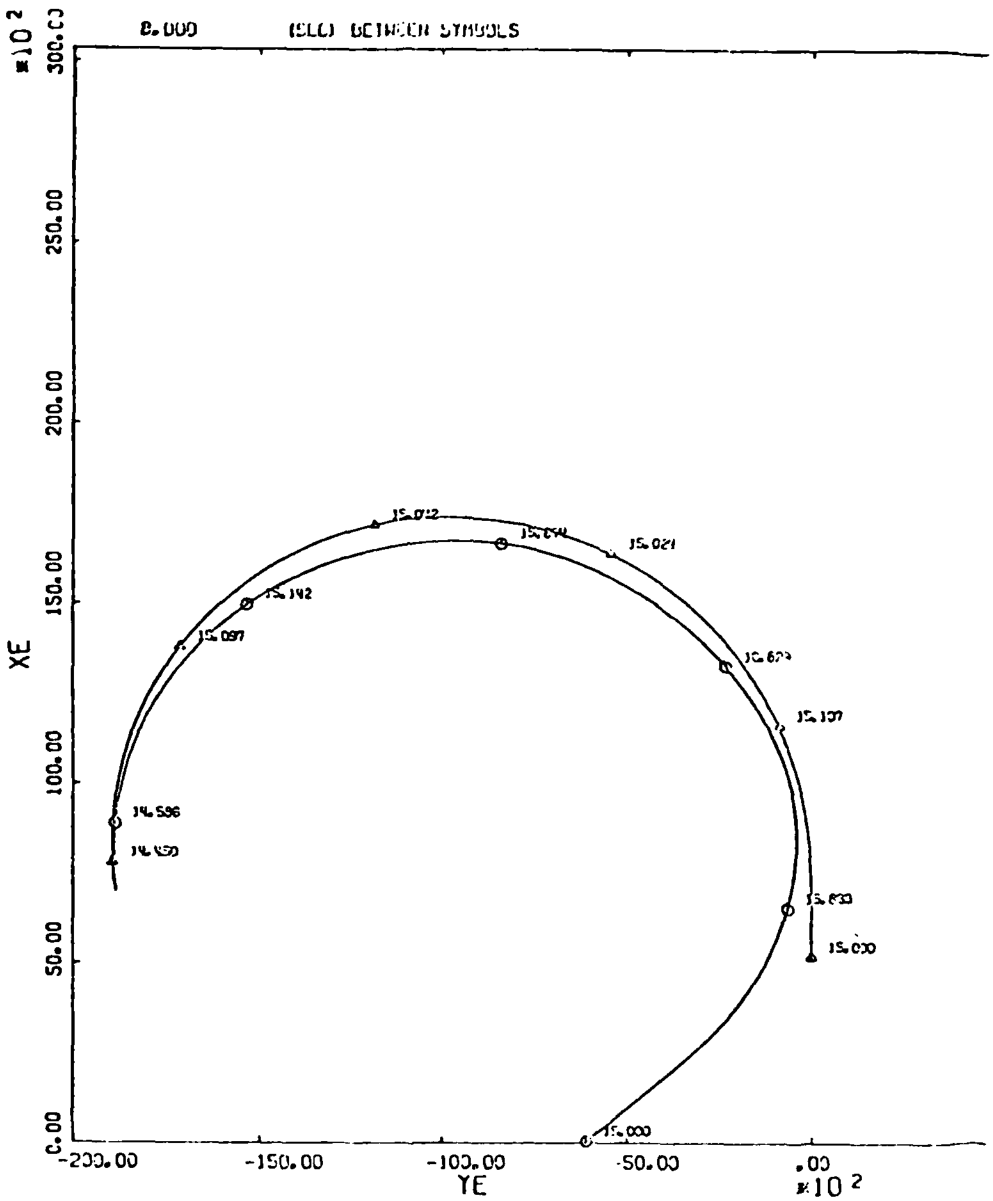

Figure 4. Ground trace for reference flight #22.

flightpath data. The radius of curvature was used to compute the load factor by the formula.

$$\text{load factor} = V^2/R = g \cos \Theta \cos \Phi$$

where V is velocity of aircraft, R is radius of curvature, Θ is pitch angle, and Φ is roll angle.

The radius of curvature is calculated as the radius of the circle through the present position of the plane and previous and next positions. If the three positions are (x_1, y_1, z_1), (x_2, y_2, z_2), and (x_3, y_3, z_3), then the center of the circle (x, y, z) is the solution of the following three equations:

$$2(x_2-x_1)x+2(y_2-y_1)y+2(z_2-z_1)z = x_2^2+y_2^2+z_2^2-(x_1^2+y_1^2+z_1^2)$$

$$2(x_3-x_2)x+2(y_3-y_2)y+2(z_3-z_2)z = x_3^2+y_3^2+z_3^2-(x_2^3+y_2^3+z_2^3)$$

$$ax + by + cz = 1$$

where (a, b, c) is the solution set of

$$\begin{pmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ x_3 & y_3 & z_3 \end{pmatrix} \begin{pmatrix} a \\ b \\ c \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$$

The radius R is then given by

$$\sqrt{(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2}$$

and if (x_2, y_2, z_2) is present position

$$V^2 = \dot{x}_2^2 + \dot{y}_2^2 + \dot{z}_2^2$$

A subroutine was then written to read the positional and velocity data from the magnetic tape and do the above computation for the load factor at each point in the flightpath. This subroutine was incorporated into the AML program.

AML Evaluation Run

The original AML program was run against the target. Two runs were made, but neither was a high-speed yo-yo maneuver. When the modified AML was run against the target, it did fly a high-speed yo-yo similar to the reference yo-yo. Several runs were made using different weights and tilt angles, but except for runs with some weights set to zero, there were no noticeable differences in the maneuvers.

During these runs, it was discovered that the program did not update the velocity during the trial maneuvers. This problem was corrected. (A more detailed account of this section is given in Appendix A.)

Reexamination of Question Set

Since varying the weights, other than setting them to zero, did not really yield different high-speed yo-yo maneuvers, the questions were reexamined. For the trial maneuvers, the throttle setting depends on the initial conditions of the trial maneuver and so is the same for all trial maneuvers at a given decision point. The load factor is a parameter dependent on other factors at the start of the trial maneuver and is constant throughout the maneuver. Therefore, it was decided to delete the questions on throttle setting and load factor. Further, since altitude is a function of altitude rate and initial conditions, and range is a function of range rate and initial conditions, they are somewhat redundant. Also, the questions considered only the magnitude (absolute value) of the error ignoring whether the error was high or low. In addition, some of the original questions of the AML program appear to be apropos to the high-speed yo-yo. Based on these observations, the following set of questions was developed and incoporated in the AML program.

1. Is opponent in front of me?

2. Can I see opponent?

3. Can opponent not see me?

4. Is my altitude rate not too low?

5. Is my altitude rate not too high?

6. Is my range rate not too low?

7. Is my range rate not too high?

8. Is my velocity not too low?

9. Is my velocity not too high?

10. Is my LOS angle within limits?

11. Is my LOS angle rate favorable?

For altitude rate, range rate, velocity, and LOS angle, envelopes were developed around the corresponding reference values as functions of time and were read in as data. An affirmative answer is given for "not too low" if the value for the parameter is above the lower limit of its envelope and for "not too high" if the value is below the upper limit of its envelope. LOS angle is within limits if it is between the upper and lower limits of its envelope. LOS angle rate is favorable if, when LOS angle is high, the rate is negative, if, when LOS angle is low, the rate is positive, or if, when LOS angle is within limits, the rate will not take it out of the envelope within the next second.

A run was made with reference flight #14 and weights all equal to 5. The result was a high-speed yo-yo but, again, with a lower apex and also with the apex occurring 2 seconds earlier than the referenced yo-yo. Plots are given in Figures 5 and 6.

As reported earlier, since the purpose was to model the referenced high-speed yo-yo, it was decided to use as base plane in the trial maneuvers the plane determined by the velocity vector and the projected position of the referenced high-speed yo-yo. This was implemented in the program. Runs were then made with run #14 as reference, with the new question set, and with the new trial maneuvers. Weights were all 5's and tilt angle was 10 degrees. Prediction times (times into the future for which the student flights were extrapolated) were 2 seconds and 3 seconds. Both runs had slightly higher apexes with the 3-second run being the better of the two. Due to a nonrecoverable tape error, the plot data for the 3-second run were lost. Plots for the 2-second run are given in Figures 7 and 8.

While the new question set was not a decided improvement over the first set of questions in matching the reference yo-yo maneuvers, it was more amenable to application of the techniques developed in Phase I for deriving an independent set of inequalities from the AML

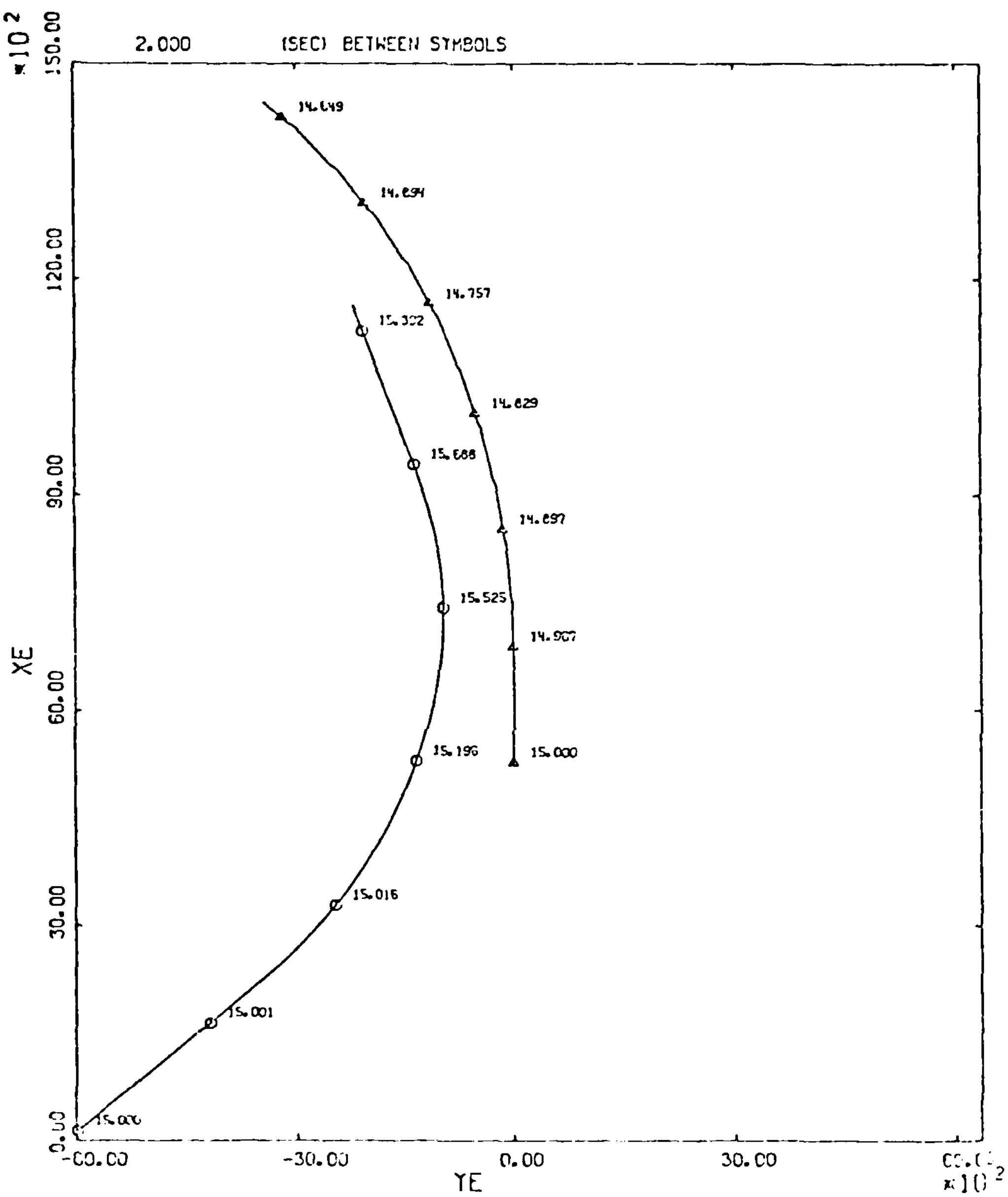

Figure 5. Ground trace. AML versus LUKE #14. Weights all 5's. Tilt angle 10°. New question set.

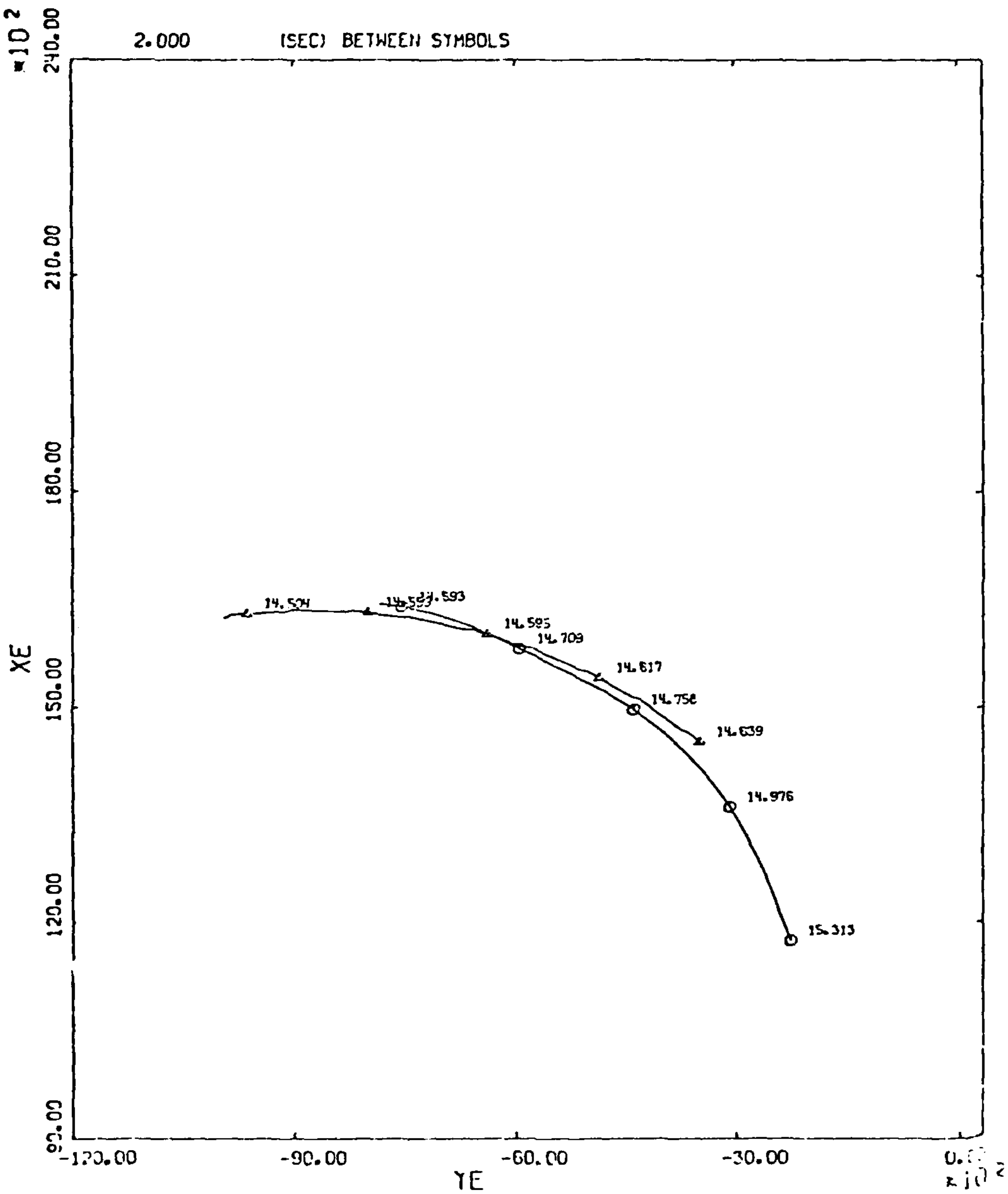

Figure 5 (Concluded).

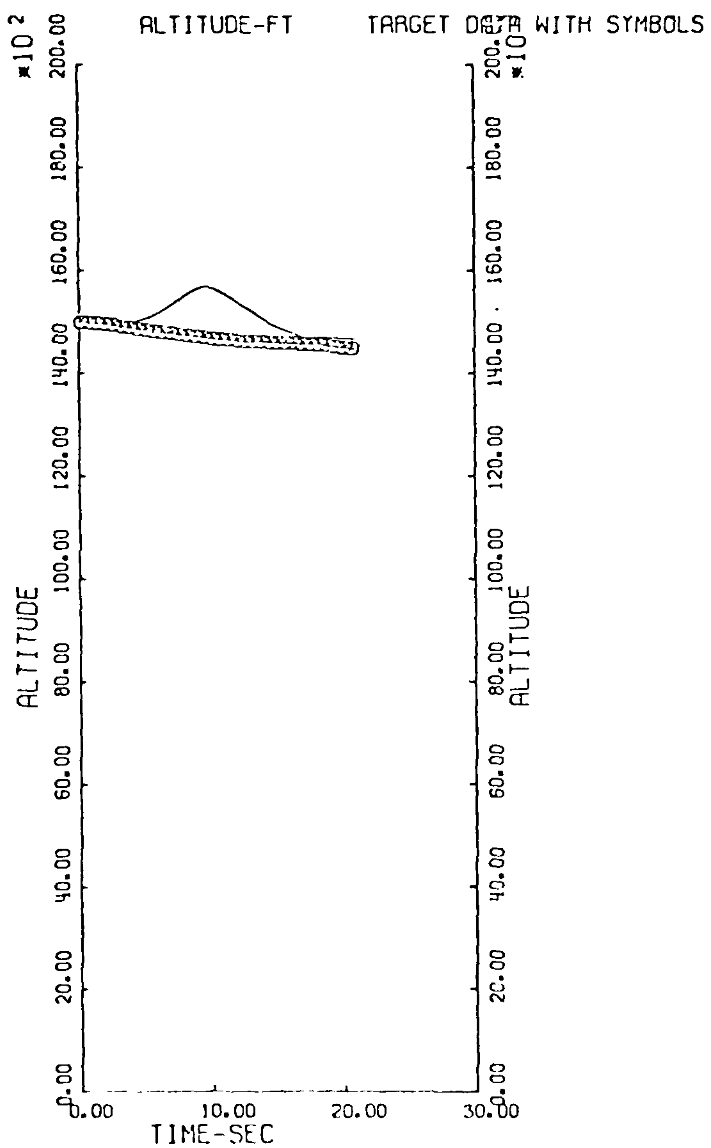

Figure 6. Altitude plot. AML versus LUKE #14. Weights all 5's. Tilt angle 10°. New question set.

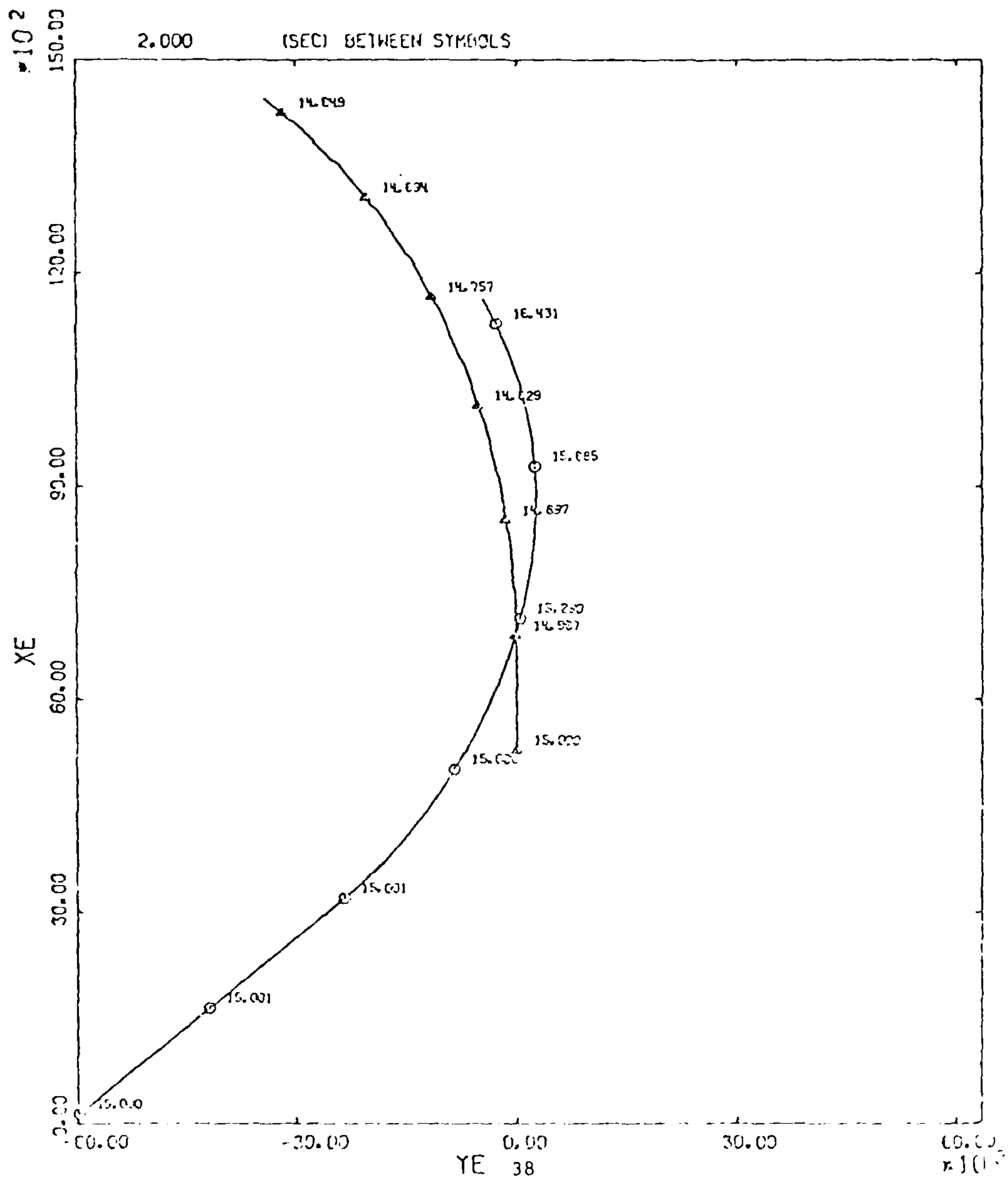

Figure 7. Ground trace. AML versus LUKE #14. Weights all 5's. Tilt angle 10°. New question set. New set of trial maneuvers.

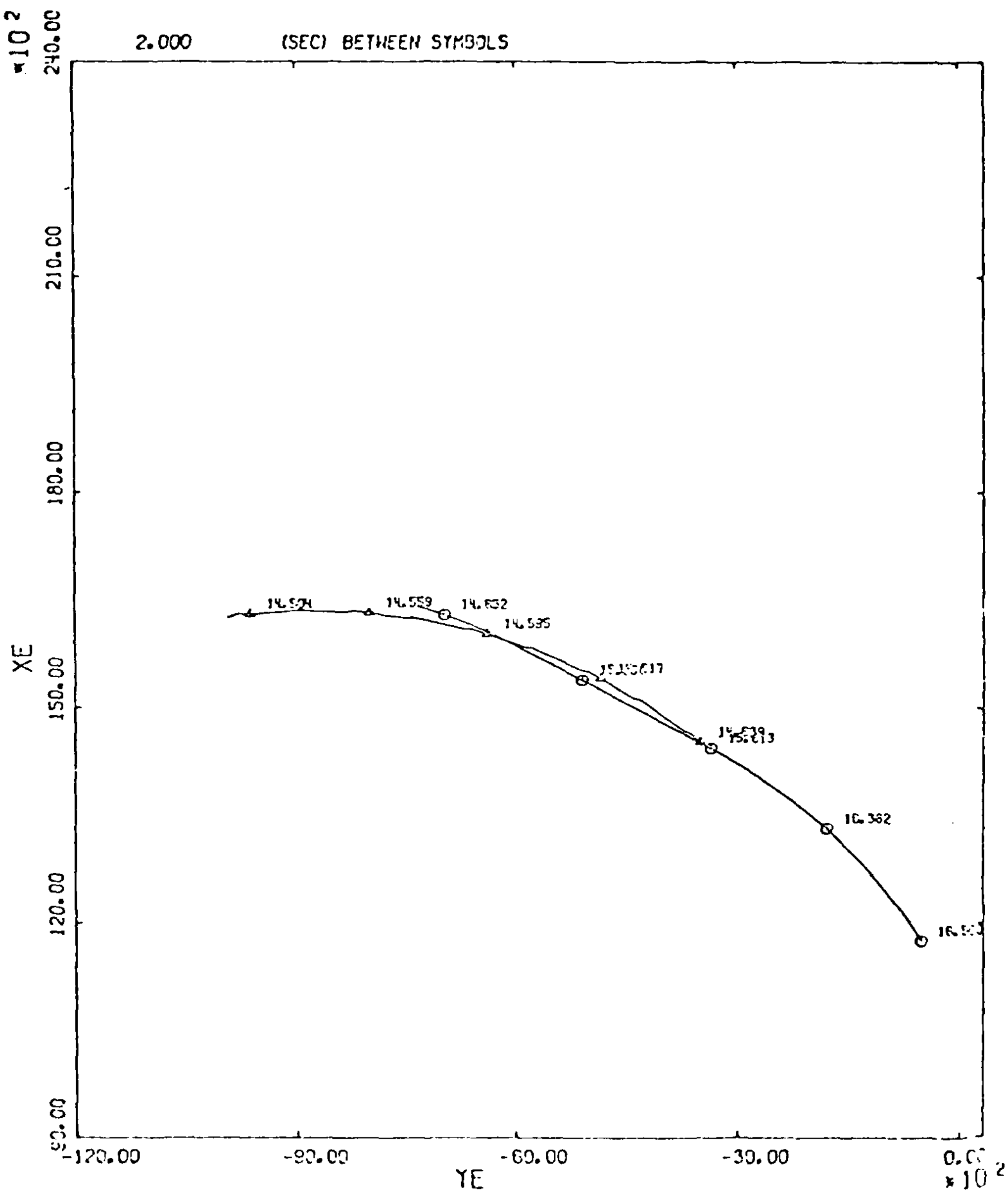

Figure 7 (Concluded).

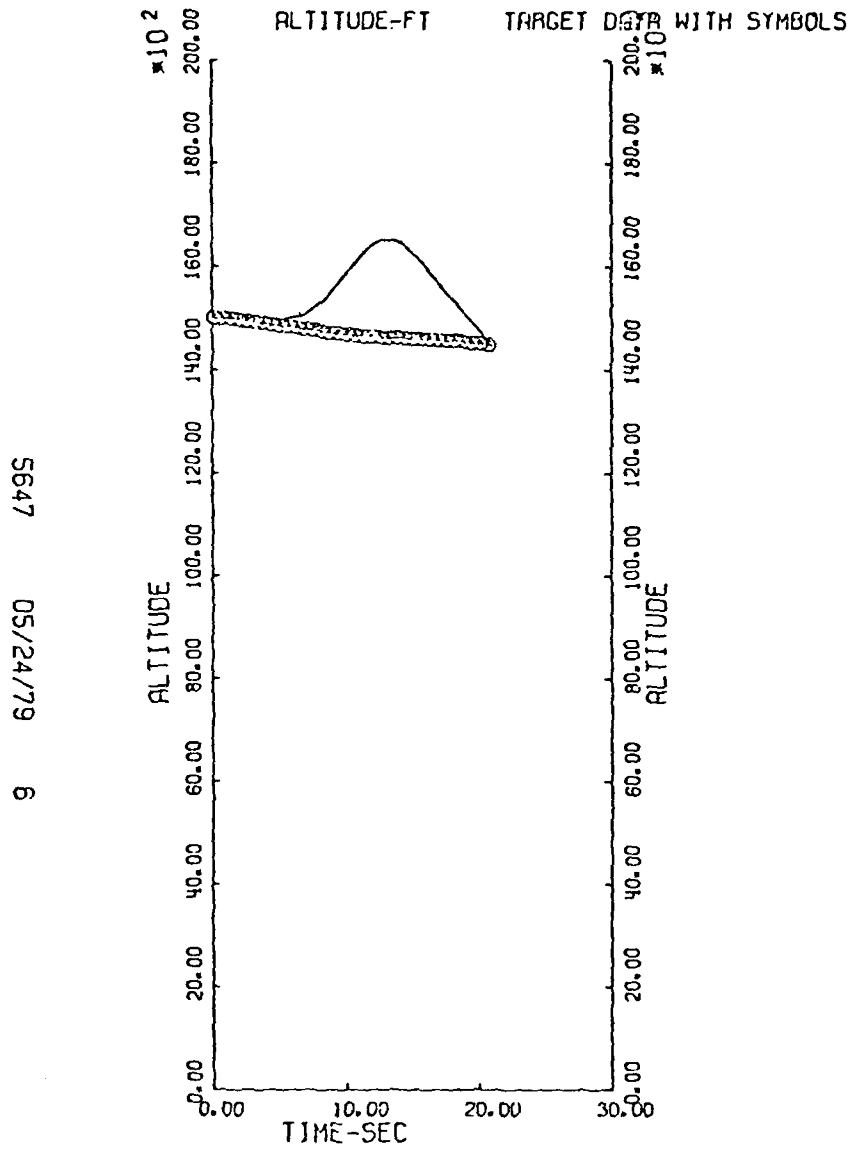

Figure 8. Altitude plot. AML versus LUKE #14. Weights all 5's. Tilt angle 10°. New question set. New set of trial maneuvers.

program and solving them by linear programming. It was, therefore, used in running the AML with the student pilot flight data to determine the apparent weights of the student pilot with respect to the questions.

Student Pilot Data

Data were obtained from 20 high-speed yo-yo maneuvers flown by five student pilots (4 flights each) on the SAAC simulator against defensive turns flown by an instructor pilot. Initial conditions for all runs were: angle off of 50 degrees, velocity of 550 KIAS, range of 8,000 feet, and altitude of 15,000 feet. The target aircraft had 375 KIAS velocity and altitude of 15,000 feet and was to fly a 3g defensive turn. The data were converted into the format necessary for use in the AML program on the CDC 3600.

At each decision point (every second), the AML program was reinitialized to the current position of the student pilot's flight from which position it set up the trial maneuvers. For each of the reference runs, two sets of inequalities were derived; one in which the student pilot's position at the prediction time was compared with all the trial maneuvers and a second in which it was compared only with the best trial maneuver (best in the sense that it was the trial maneuver which had the most questions answered affirmatively). Hence, for each of the 20 student flights, 4 different sets of weights were computed.

In Phase I, weights in the LP program were restricted to be between 1 and 5. Since the AML is deterministic and consistent in its decisions, solution with these restrictions always existed. Hence, minimum and maximum solution could be found which gave bounds on the possible solutions; however, when the LP program with these restrictions was run on the student pilot data, no solution existed. This means that for the student pilots it is not possible to find a set of positive weights that will satisfy the set of inequalities. The requirement that the weights be greater than or equal to one had to be dropped and zero weights admitted. The minimum solution then consists of all zeros and does not add any information. Hence, only the maximum solution was obtained by the LP program.

Summary

Information in the question set should be adequate for the AML to fly a high-speed yo-yo maneuver and should also be meaningful to the pilot. It should be directly displayed or relatively easily perceived by the pilot. Further, the criteria for correct values should involve the reference yo-yo's. On the basis of these requirements the above list of questions was developed.

Four new maneuvers were added to the set of trial maneuvers, and the base plane was changed to be the plane defined by the AML's velocity vector and the projected position of the reference yo-yo.

Using initial conditions that would require the immediate execution of a high-speed yo-yo maneuver, two instructor pilots on the SAAC at Luke AFB each flew six runs against a noninteractive target flying a 3g defensive turn. The best high-speed yo-yo maneuver of each pilot was chosen as a reference yo-yo.

In Phase I, it was discovered that the recorded normal acceleration along the z-axis did not always agree with that computed by the AML using associated recorded flightpath data. This disagreement also occurred in the high-speed yo-yo data. To solve this problem it was decided to use computed normal acceleration rather than the recorded data. A subroutine was written to compute the normal acceleration from positional and velocity data of the yo-yo maneuver and was incorporated into the program.

Both the original and the modified AML program were run against the target airplane. The original AML did not fly a high-speed yo-yo, but the modified program did. Several runs were made by the modified AML, but it was not sensitive to weight changes except when some weights were set to zero.

An analysis showed that two parameters in the question set were not updated in the trial maneuvers and so did no differentiating, that other parameters had redundancies in them and that the questions considered only the magnitude of the error ignoring whether the error was high or low. A new set of questions were developed and tested. While it was not a decided improvement over the old set, it was more amenable to the techniques developed in Phase I. It was decided to use the new set.

Data were obtained from 20 high-speed yo-yo maneuvers flown by student pilots on the SAAC simulator with the same initial conditions as for the reference yo-yo maneuvers. Five pilots each flew 4 maneuvers. By having the AML reinitialized at each decision point to the current position of the student's flight from which point it set up the trial maneuvers, the AML was able to compare the student pilot's projected position with that of each trial maneuver. This gave rise to sets of inequalities from which the student pilot's weights could be determined. Unlike the AML, the student pilots were not deterministic so that nonzero solutions to the inequalities did not exist. Zero weights had to be allowed in order to get solution sets.

III. EXPERIMENTAL RESULTS

Each student flight was run twice against each of the reference flights, once comparing the student pilot's position at prediction time with all trial maneuvers and second, comparing it only with the best trial maneuver. Hence, four sets of inequalities and, therefore, four sets of weights were obtained for each of the 20 student flights. The weights for each set obtained using the maximum solution of the LP program are given in Table 1. To simplify the table, only the questions with nonzero weights are listed. Unless indicated, weights are assumed to be 5. Student flight #12 with respect to reference flight #14 and using the best trial maneuver for comparison had nonzero weights of 5 and 2.5. Those questions having weights of 5 are listed in the first row, and those with weights of 2.5 are listed in the second row. The same is done for flight #15 with reference flight #22 and all trial maneuvers for comparison.

In general, for each flight the four sets of weights show good consistency; but little or no consistency is evident across the four flights for each student. As a check on this lack of consistency, the inequalities for all four flights for each student pilot with reference flight #14 were combined and solved. Student pilots 1 and 4 had nonzero weights only on questions 1 and 9, while the other student pilots had nonzero weights on questions 1 and 2. These were the only questions on which the respective pilots had essentially unanimous affirmative answers over all flights.

Basic Difficulties in Method

Since they will be referred to in the discussion and analysis, the following tables are introduced here: Table 2, Code in Octal Cell Number for Question Number[1]; Table 3,

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[1]At each decision point, the student pilot and each trial maneuver are assigned a cell number which is a binary number in the computer (but printed as an octal number) with a 1 in each binary position corresponding to questions with a yes answer. Therefore, octal number 1342 would indicate yes answers to questions 2, 6, 7, 8, and 10. Codes in 1342 are 2, 40, 100, 200, and 1,000 which by Table 2 correspond to questions 2, 6, 7, 8, and 10, respectively.

TABLE 1

Questions with Nonzero Weights Determined by AML for Student Flights
Questions listed have weights of 5 (unless otherwise indicated)

Student 1

	File 1	File 2	File 3	File 4
#14--Best	1,2,4,5,7,9	1,3,4,6,8,9	1,4,5,9	1,3,4,5,9
#14--All	1,2,4,5,7,9	1, ,8,9	1, ,9	1,3,4,5,9
#22--Best	1,2,4,5,7,9,10,11	9	1,4,5,9	1, ,4,5,9
#22--All	1,2,4,5,7,9,10,11	9	1, 9	1, 9

Student 2

	File 5	File 6	File 7	File 8
#14--Best	1,2, ,7	1,2,6,7, ,9	1,2,3,4,5,6,7	1,2,4,7,9
#14--All	1,2, ,7	1,2, ,9	1,2,3,4,5	1,2 ,9
#22--Best	1,2,3,7	1,2, ,7,8,9	1,2,4,5,7,8,9,10,11	None
#22--All	1,2, ,7	1,2, ,7,8,9	1,2,5,6,7,8,9.10,11	None

Student 3

	File 9	File 10	File 11	File 12
#14--Best	1,2,3,5,10,11	1,2,3,4,5,6,7,9,10	1,2,3,6,7,8,10	1,2,3,4,6,7,9--5 5,10,11 --2.5
#14--All	1,2,3, 11	1,2,3,4,5,6,7,9,10	1,2,3,6,7,8,10	1,2,3,4,5,7,9
#22--Best	1,2,5,7,10,11	1,2, ,6,7,9,10	1,2,3,6,8,9,10	1,2,4, ,7,9
#22--All	1,2, 7,10	1,2, ,6,7,9,10	1,2,3,6,8,9,10	1,2,4, ,7,9

TABLE 1 (Concluded)

Student 4

	File 13	File 14	File 15	File 16
#14--Best	1,2,3,4,7,8,9,10,11	1,3,4,8,9,10,11	1,2,4,6,7,9,10,11	1,3,6,8,9,10
#14--All	1,2,3,4,7,8,9	1,3, ,8,9	1,2,4, ,7,9	1,3,6,8,9,10
#22--Best	1,2, ,9	1, ,8,9	1,2,4,6,7,9	1 ,8,9
#22--All	1,2 ,9	1, ,8,9	1,2, --5 4,6,7,9--2.5	1, ,9

Student 5

	File 17	File 18	File 19	File 20
#14--Best	1,2,9	1,2,3,5,6,8,9,10	1,2,4,5,9,11	1,2,3,5,6,8,9
#14--All	1,2,9	1,2,3,5,6,8,9,10	1,2,4,5,9,11	1,2, ,8,9
#22--Best	1,2,5,7	1,2, ,5, ,9	1,2, ,5,7	1,2, ,5, ,9
#22-All	1,2	1,2	1,2, ,7	1,2, ,9

TABLE 2

Code in Octal Cell Number for Question Numbers

Question	Code	Question	Code
1	1	7	100
2	2	8	200
3	4	9	400
4	10	10	1,000
5	20	11	2,000
6	40		

TABLE 3

Octal Number Pairs Describing Inequalities with Reference Run #14 and Best Trial Maneuvers

File 1

0	3000
1120	250
3000	240
100	240
0	40
2100	60
2100	50
2102	44
110	64
0	4

File 2

0	3000
40	3102
0	2102
0	22

File 3

1000	240
0	1002
10	3020
0	2042
20	50
0	2202
50	2122
10	2024

File 4

0	3100
20	1050
40	2302
60	2112
20	110
0	102
10	122

File 5

200	1000
20	10
0	40
200	400
0	2000
0	200
0	20
10	24

File 6

0	10
40	3100
0	2200
2000	1000
2010	1020
10	2024

File 7

20	2010
220	3010
420	3010
60	3010
40	2100
0	400
2000	200
1000	2000

File 8

50	3120
0	2220
0	4
0	3040

File 9

220	1410
0	50
200	500
0	300

File 10

20	10
0	2000
0	200

File 11

10	2420
0	2000
0	10

File 12

0	200
400	3200
1010	2200
10	220
3010	60
10	1020
2410	264
2510	264
2110	244
2010	204

TABLE 3 (Concluded).

File 13

50	120
10	2020
0	20
10	60
0	40
1102	44

File 14

50	1120
50	2120
10	120
0	42
10	60
0	20

File 15

0	224
410	320
450	3320
2010	1324
100	40

File 16

50	1120
50	2120
10	120
0	20
0	102
40	2112
20	2112
40	1102

File 17

1020	14
100	240
60	10
400	300
2000	300
0	20
1000	2200
0	3000

File 18

40	3100
0	110
20	2110
0	2000
20	410
400	210

File 19

40	300
1400	300
60	1110
2220	1110
0	100
0	244
0	1000

File 20

0	100
0	10
1000	2010
0	3000

Octal Number Pairs Describing Inequalities with Reference Run #14 and Best Trial Maneuver; Table 4, Position of Student Pilots and Instructor Pilots at 0, 10, and 17 *seconds*[2]; Table 5, Cell Numbers in Octal for Decision Points in Student Flights; and Table 6, General Description of Student Flights, Comparisons with Reference Flight #14.

While the score for a student pilot at a decision point is determined by the position relative to the reference yo-yo, the inequalities which are used in determining the weights depend on both the position of the student pilot and the projected position of the trial maneuvers of the AML. For example, even though the student pilot has a negative answer to a question at all decision points, if the AML does likewise, the question will not appear in the inequalities and will receive the maximum weight. As can be seen from Table 5, in flight #10, questions 7 and 10 (code 100 and 1,000) never had an affirmative answer at a decision point; but as can be seen from Table 3, the codes did not appear in any of the inequality pairs for flight #10. Hence, none of the best trial maneuvers ever had an affirmative answer to these questions; and so as shown in Table 1, both questions had a weight of 5.

Unlike the AML, the student pilot can choose a definitely inferior maneuver whose set of affirmative answers is a subset of the affirmative answers of the trial maneuvers. This results in the first number of the inequality number pair being zero, so zero weights have to be assigned to any question whose code appears in the second number. All student flights had at least one such maneuver at some decision point (reference Table 3). In over half the flights, the zero weights had a cascading effect in that codes for questions with zero weights occurred in the first number of other inequalities making the first number a zero. Extreme cases are flights #5 and #17. In both cases, all questions whose codes appeared in the second number of an inequality pair had to be assigned weights of zero (reference Tables 1 and 3). Flight #17 was one of the better flights (reference Tables 5 and 7).

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[2]These are actually 4, 14, and 21 seconds into the flight as the program at Luke at the time of student pilot flights did not start recording data until 4 seconds into the flight. The times on the instructor pilot data were adjusted to match. The total time on reference flight #14 is 24 seconds so with prediction time of 3 seconds only 21 seconds can be used by the AML or, after adjustment, 17 seconds when #14 is used as reference.

TABLE 4

Position of Student Pilots and Instructor Pilots at 0, 10 and 17 Seconds

Student Flights

	x_0	y_0	z_0	x_{10}	y_{10}	z_{10}	x_{17}	y_{17}	z_{17}
File 1	2,982	-2,929	15,438	11,152	-2,845	16,378	12,542	-8,020	14,920
File 2	3,022	-2,895	15,391	10,893	-2,791	15,329	12,477	-7,537	15,704
File 3	3,198	-3,037	15,400	11,907	-3,476	16,539	15,311	-8,088	16,698
File 4	3,022	-2,919	15,225	11,266	-2,865	14,456	14,705	-7,018	15,374
File 5	2,962	-2,772	14,831	12,527	-618	15,024	15,641	-4,900	16,015
File 6	3,048	-2,711	14,948	12,967	-532	14,844	16,133	-4,494	15,899
File 7	2,937	-2,799	14,813	12,475	-134	13,129	15,243	-6,458	13,787
File 8	2,936	-2,748	14,940	11,155	-699	17,214	14,250	-3,367	16,171
File 9	2,919	-2,830	14,855	12,853	-593	13,410	16,929	-5,826	13,910
File 10	2,955	-2,742	14,825	12,872	973	14,521	17,004	-3,003	16,364
File 11	2,979	-2,680	15,248	12,561	2,161	17,485	20,036	-95	16,534
File 12	2,946	-2,840	15,304	11,692	-1,977	16,539	15,416	-6,929	15,530
File 13	2,878	-2,813	15,146	10,490	-1,039	17,931	13,767	-5,502	16,365
File 14	2,833	-2,840	15,191	9,927	-1,755	19,014	12,458	-6,372	18,247
File 15	2,982	-2,837	15,196	11,791	-1,800	17,411	15,885	-6,232	16,479
File 16	2,886	-2,855	15,216	9,927	-1,564	19,271	11,070	-5,929	19,205
File 17	2,833	-2,815	15,254	11,244	-1,034	15,389	14,447	-5,973	14,776
File 18	3,059	-2,732	15,111	13,225	787	16,269	18,162	-3,565	14,524
File 19	3,044	-2,751	15,246	12,086	-860	15,900	14,800	-4,265	14,966
									(15 sec)
							(15,645	-5,539	15,206)
								=14	@ 15 sec
File 20	2,927	-2,707	15,177	10,717	-464	16,640	14,062	-4,817	15,383

Instructor Pilot Flights

	x_0	y_0	z_0	x_{10}	y_{10}	z_{10}	x_{17}	y_{17}	z_{17}
#14	3,332	-2,769	14,995	13,024	-1,932	16,236	16,075	-7,344	14,858
#22	3,036	-2,647	14,857	11,864	-1,337	16,835	15,937	-5,815	16,293

TABLE 5

Cell Numbers in Octal for Decision Points in Student Flights

T \ File	1	2	3	4	5	6	7	8	9	10	11	12
0	453	453	453	453	463	463	463	453	463	463	453	453
1	453	453	453	453	463	667	463	453	463	463	457	453
2	451	451	1,473	463	1,467	3,267	3,467	457	463	267	257	451
3	453	3,463	3,563	463	3,567	2,327	2,567	457	3,567	267	277	453
4	2,563	523	3,523	523	2,527	3,327	2,527	457	1,327	267	277	3,463
5	3,523	523	1,523	523	2,727	3,327	1,527	457	327	267	257	1,563
6	523	523	521	2,523	3,727	3,327	727	457	327	267	257	523
7	523	523	533	2,523	317	3,377	727	2,457	267	267	257	523
8	523	2,523	2,513	461	257	257	367	2,457	267	257	257	523
9	523	1,563	2,533	463	257	657	2,257	2,457	267	257	257	1,523
10	1,523	463	2,523	463	257	457	2,257	2,457	257	257	257	3,513
11	3,523	453	2,511	453	457	457	2,657	2,453	2,257	2,257	257	3,713
12	513	453	511	2,453	2,457	2,457	2,457	2,457	2,257	2,457	257	2,713
13	513	451	513	2,553	2,457	2,457	2,457	2,457	2,257	2,457	2,257	2,713
14	2,513	453	513	2,513	2,457	2,457	2,457	2,457	2,257	2,457	257	2,713
15	2,523	453	451	453	2,457	2,457	2,457	2,463	2,251	457	267	2,513
16	513	453	453	453	2,457	2,457	1,457	1,463	2,257	457	2,267	513
17	513	453	2,453	2,453	2,457	2,451	1,457	1,463	2,257	2,457	2,267	2,518

TABLE 5 (Concluded)

	13	14	15	16	17	18	19	20
0	453	453	453	453	453	453	453	453
1	453	453	453	453	453	657	453	453
2	451	451	453	451	451	267	453	453
3	453	453	1,463	453	463	267	473	457
4	453	453	1,563	453	2,463	267	2,463	2,457
5	453	453	1,557	453	1,463	267	2,467	2,467
6	2,453	453	457	453	527	267	3,467	2,467
7	2,453	2,453	457	2,453	527	267	3,567	2,467
8	2,453	2,453	2,457	2,453	1,567	267	3,467	1,467
9	2,453	2,453	2,457	2,453	3,467	257	2,467	1,467
10	2,553	2,453	2,453	2,453	3,467	277	2,667	1,467
11	2,513	2,453	2,453	2,453	3,457	267	2,667	1,473
12	2,513	2,553	2,453	2,453	1,457	2,267	2,657	1,453
13	2,513	2,513	2,453	2,453	1,457	2,267	2,457	1,453
14	2,523	2,513	2,453	2,453	3,457	2,267	2,557	3,553
15	2,523	2,513	2,553	2,451	457	2,267	3,517	3,513
16	3,523	2,523	2,523	2,461	457	2,267	---	3,513
17	3,523	2,521	2,523	461	457	2,667	---	3,513

TABLE 6

General Description of Student Flights
Comparisons are with reference flight #14.

File	
1	High-speed yo-yo with apex higher and 2 seconds early--fair ground trace
2	High-speed yo-yo with apex higher and 3 seconds early but started up again in the middle of descent--fair ground trace
3	High-speed yo-yo with apex higher and at the same time but started up again in the middle of descent--fair ground trace
4	High-speed yo-yo with low apex, 4 seconds early followed by a low-speed yo-yo--fair ground trace
5	Low-speed yo-yo followed by high-speed yo-yo--fair ground trace
6	Low-speed yo-yo followed by high-speed yo-yo--fair ground trace
7	Low-speed yo-yo with good ground trace
8	High-speed yo-yo with very high apex, 2 seconds late--poor ground trace
9	Low-speed yo-yo with fair ground trace
10	Low-speed yo-yo followed by high-speed yo-yo--very poor ground trace
11	High speed yo-yo with very high apex, 3 seconds late--worse ground trace
12	High-speed yo-yo with slightly higher apex, 1 second early--good ground trace
13	High-speed yo-yo with high apex, 1 second late--fair ground trace
14	High-speed yo-yo with high apex, 3 seconds late--poor ground trace
15	High-speed yo-yo with high apex, 2 seconds late--good ground trace
16	High-speed yo-yo with high apex, 5 seconds late--poor ground trace
17	High-speed yo-yo with same apex, 3 seconds early--fair ground trace
18	High-speed yo-yo with same apex at same time--fair ground trace
19	High-speed yo-yo with same apex, 2 seconds early--good ground trace
20	High-speed yo-yo with high apex, 1 second early--fair ground trace.

TABLE 7

Number of Affirmative Answers per Question
with Reference Flight #14
Maximum number per question is 18 except for file 19,
which has a maximum of 16 per question.

File	1	2	3	4	5	6	7	8	9	10	11
1	18	17	0	9	9	5	14	0	18	3	5
2	18	16	0	10	8	13	6	0	18	1	1
3	18	14	0	13	7	7	12	0	18	4	6
4	18	17	0	9	9	13	6	0	18	0	6
5	18	18	16	11	7	14	5	5	14	3	4
6	18	18	17	11	8	14	5	10	11	5	12
7	18	18	16	9	9	14	6	6	15	3	11
8	18	18	12	15	3	18	0	0	18	2	9
9	18	18	15	8	10	15	4	14	4	2	9
10	18	18	16	10	8	18	0	10	8	0	4
11	18	18	17	15	5	18	0	16	2	0	3
12	18	17	0	12	6	6	13	4	18	5	7
13	18	17	0	14	4	11	8	0	18	2	12
14	18	16	0	16	2	13	6	0	18	0	11
15	18	18	5	14	4	16	5	0	18	3	10
16	18	14	0	16	2	18	0	0	18	0	9
17	18	17	12	10	8	16	3	0	18	8	4
18	18	18	17	4	15	18	0	17	3	0	6
19	16	16	11	8	9	15	4	3	16	4	12
20	18	18	8	12	7	15	4	0	18	10	7

Analysis

The following analyses were made:

1. Comparison of overall flightpaths with weights for possible correlations.

2. Applicability of weights as measures of the importance attributed by the pilot to the respective questions.

3. Possibility of the AML using derived weights serving as a model of the student pilot.

Comparisons of Flights with Weights

As can be seen from Tables 4 and 6, not all flights were high-speed yo-yo maneuvers and those that were showed considerably variability. The weights of flights of the same type were studied for possible use as identifiers of the flight types. No reasonable identifiers were found. For example, flights #1, #12, and #20 were high-speed yo-yo maneuvers but have quite different weights. Similar results hold for flights #7 and #9 which were low-speed yo-yo maneuvers and for flights #5, #6, and #10 each of which was a low-speed yo-yo followed by a high-speed yo-yo. From a different view point, flights #3 and #4 have same weights in relation to reference flight #22 but are quite different flights types. A similar result holds for flights #10 and #12 with reference flight #14 and best trial maneuver.

Weights as Measures of Importance

If the weight is to measure the importance attributed by the pilot to a question, the number of affirmative answers to each question must be involved in the judgment criterion. Now, for all practical purposes the assignment of weights is dichotomous in that either the maximum value of 5 or the minimum value of 0 is assigned in almost all cases. This seems to indicate a threshold as criterion; i.e, if the percentage of affirmative answers is above the threshold, a weight of 5 should be assigned, otherwise, a weight of 0. From Table 5, Table 7 was constructed showing the number of affirmative answers per question for each flight with reference flight #14. Using this table in conjunction with Table 1, the percentages of correct nonzero weights, of correct zero weights, and of correct

total weights were computed for two thresholds, one of 67 per cent and the other of 50 per cent. The results are shown in Table 8. These results show a large variance over the flights with an average total correct for each threshold of around 66 per cent. As would be expected, the lower threshold increased the percentage correct of nonzero weights but decreased the percentage for zero weights correct. A random selection would give around 50 per cent correct so the 67 per cent correct is not appreciably better than random. Moreover, the per cent correct varies over the different flights from 46 to 82. This would appear to rule out the assigned weights as good measures of the importance attributed by the pilots to the different questions.

AML as Model of Student Pilot

In Phase I of this study, the minimum and maximum solution gave limits on possible solutions for the set of weights. Any such solution, if used as weights in the AML program, would cause it to fly the observed engagement exactly as the observed AML program did. If the weights obtained for a student pilot against a reference flight were used in the AML flying against the same reference flight, would the AML fly the same pattern as the student did? Most likely, it would not. As previously reported, different student flights had the same set of weights, but their flight patterns were very different. Obviously, the AML cannot model both. Also, when the AML was given zero weights for two questions, it flew a high-speed yo-yo against one reference flight but a low-speed yo-yo against the other. Further, at many decision points, the cell number resulting from student pilots' maneuvers was not a cell number resulting from one of the trial maneuvers. Hence, there is no guarantee that the best trial maneuver for the AML would adequately approximate the student pilot's maneuver at each decision point. Actually, at any decision point, it is unlikely that the student's maneuver would be exactly one of the trial maneuvers increasing the probability of large accumulated errors in the flight's parameters.

Other Anomalies

As can be seen from Tables 4 and 6, student flights #10 and #11 were very poor flights, but both have most weights nonzero, particularly flight #10. In student flights #10 and #11, the values of the parameters are far from the boundaries of the envelope of parameter values

TABLE 8

File	Per Cent Nonzero Weights Correct		Per Cent Zero Weights Correct		Per Cent Total Correct	
	Threshold 67%	50%	Threshold 67%	50%	Threshold 67%	50%
1	67	67	100	100	82	82
2	50	67	80	80	64	73
3	75	75	86	72	82	73
4	40	40	67	67	55	55
5	67	67	63	50	64	55
6	60	80	83	33	73	55
7	57	57	75	50	64	55
8	80	80	83	67	82	73
9	50	67	60	60	55	64
10	44	56	100	50	55	55
11	72	72	75	75	73	73
12	72	72	100	100	82	82
13	44	56	100	50	55	55
14	43	57	50	50	46	55
15	63	75	100	100	73	82
16	50	50	60	60	55	55
17	100	100	75	63	82	73
18	75	75	100	100	82	82
19	50	83	80	60	64	73
20	57	57	100	50	72	55
Overall	59	66	79	66	67	66

around the reference parameter values. As a result, the cell numbers of the student pilot maneuver as well as those of the trial maneuvers varied very little during the flight. Hence, few inequalities were generated or, equivalently, few questions had restrictions on their weights. Thus, most of the questions received weights of 5.

Surprisingly, a very good high-speed yo-yo would probably not give rise to many inequalities; for example, a high-speed yo-yo whose parameter values were always within the envelope of parameter values of the reference flight would have yes answers to all questions. Hence, there would be no questions peculiar to the trial maneuvers, and the second number in the inequality pair would always be zero. The resulting inequality is simply that the sum of the weights for questions peculiar to the good yo-yo is greater than or equal to zero. But this is already part of the LP program restrictions, and the pair would be disregarded. However, a good yo-yo would have consistently high scores (10 or 11 out of 11) while a poor one would not.

As previously shown in the report, the AML with weights all equal to 5 flies a high-speed yo-yo which is a good approximation to the reference yo-yo. Hence, it would model the good high-speed yo-yo.

Application of a Modified AML

The data in Table 5 are descriptive of aspects of the student pilot's performance, some relative to the target aircraft, and others relative to the reference flight. They are a history of his performance relative to the question set; for example, the results for flights #1 through #4 show that student pilot #1 consistently stayed behind the target (question 1, code = 1), almost always had the target in sight (question 2, code = 2), but was always in view of the target (question 3, code = 4).

The derivation of the data in this table does not involve the part of the AML program which determines the next AML maneuver at each decision point and flies the AML. Hence, the usual restriction that the set of questions be amenable to that part of the AML logic which determines the next maneuver no longer holds. A set of questions can be used which involves those aspects of the flight which are of interest to the instructor.

The modified version (actually a stripped down version) of the AML can determine and store these data for later extraction and display.

IV. CONCLUSION

In Phase I, the basic methodology was developed for computing the weights from recorded flight data. Here in Phase II, the approach was refined based on the experience in Phase I and was evaluated using real world data recorded on the SAAC at Luke AFB. The evaluation revealed the following critical problems in this approach.

AML and LP

The refined AML program was run against the student flight data to determine in conjunction with a linear programming (LP) program the appropriate weights of the student pilot with respect to the question set. In all cases, the resulting inequalities required that some of the weights be zero in order to obtain a solution; thus, the restriction that the weights be between 1 and 5 had to be dropped. Weights were still restricted to be less than or equal to 5, and the usualy requirement of nonnegative weights remained. The result was that the sets of weights, with two exceptions, took on only the values 0 and 5. This eliminated any tight bounds on solutions except for the zero weights.

Basic Problems with Method

The inequalities derived to determine the set of weights depend on the relative position of the student flight and the AML trial maneuvers at each decision point. Hence, they do not always reflect the position of the student relative to the reference yo-yo. Also, the possibility plus the actual occurrences of definitely inferior maneuvers by the student pilots resulted in zero weights having to be allowed. Hence, when an inferior maneuver occurred, the zero weights were determined by a single decision point. In addition, there was often a cascading effect of zero weights when other inequalities had the code for questions with zero weight in the first word of the inequalities.

Weights Versus Flight Patterns

The possibility was studied of correlating with sets of weights the different types of flight patterns as

described in Table 7. No such correlations were found. Similar flights had different weight sets, and cases of completely different flights with the same weight sets were found.

Weights Versus Frequency of Affirmative Answers to Questions

To be meaningful, the weights should reflect the importance attributed to each corresponding question. On the other hand, the frequency with which each flight performance question has an affirmative answer should be a measure of its importance and, thus, should correlate with the corresponding weight. For all practical purposes, the weights are dichotomous, being either 0 and 5, thus suggesting a threshold logic. The percentage agreement between the weights and frequencies, for frequency thresholds of 50 per cent and 67 per cent, was computed for the 20 student flights. The percentage agreement varied considerably over the different flights for both thresholds with a 66 per cent agreement overall in both cases. The large variability over the different flights plus the low percentage of agreement ruled out use of the weights as measures of the importance attributed by the pilot to the various questions.

Application of Modified AML

Now, for each student flight the sequence of octal cell numbers representing the answers to the question set at each decision point is a history of his performance relative to the criteria (the question set). This history is in a form amenable to automatic extraction of data and analysis. Hence, since the requirement that the set of questions be amenable to flying the AML would not be a useful implementation, questions could be developed which involve those aspects of the flight of interest to the instructor. The modified AML program can then score the student flight at each decision point and store the sequence of scores for later data extraction and analysis.

Summary

In summary, a method that looked relatively promising during initial tests using simulated data failed when real world data from the SAAC were used. There is no evidence that the method is useful here, and some serious problems

were discovered concerning the methods employed in the approach. Based on this analysis, no further pursuit into this effort is recommended.

V. APPENDIX A

Evaluation of Original AML in Flying High-Speed Yo-Yo Maneuvers

Since in the past the original Adaptive Maneuvering Logic (AML) was not observed to fly a high-speed yo-yo, it had been assumed that it would not. To verify this, the original AML was flown against the target. In the first run, the AML kept essentially the same altitude but swung well outside the path of the attacker and then came back in behind, sort of a horizontal yo-yo; however, it was pointed out that this is not a good maneuver since the target could become the attacker and take away the positional advantage of the AML. The ground trace is shown in Figure A-1. It was noticed that the range and range rates for the first decision point were about 10 times as high as they should be. An error was found in that part of the program which saves the last three positions of the target in order to project its position at decision time. At the first decision point, only two points had been saved. This was corrected, and the original AML flown against the target. As shown in Figures A-2 and A-3, a completely different path was flown but still not a high-speed yo-yo. It used throttle settings to adjust velocity. It is suspected that it also used speed brakes, but that is not a printout item and cannot be verified without additional program modification. The result, of course, ruled out using the original AML.

Performance of Revised AML on High-Speed Yo-Yo

A subroutine in the AML program evaluates each candidate trial maneuver of the attacker using the question set. This subroutine was rewritten using the new set of questions. The new AML (i.e., using the new set of questions) did fly a high-speed yo-yo, but it did not produce as high an apex as the reference runs. It closed behind the target sooner and at a higher closing rate. Figures A-4 and A-5 represent a flight using the new AML with run #22 as reference.

Five runs were made using Luke flight #14 as the reference flight, and five were made using Luke flight #22 as the reference. In the runs, different sets of weights and/or different tilt angles were used. (In the trial maneuvers, only multiples of the tilt angle are allowed as

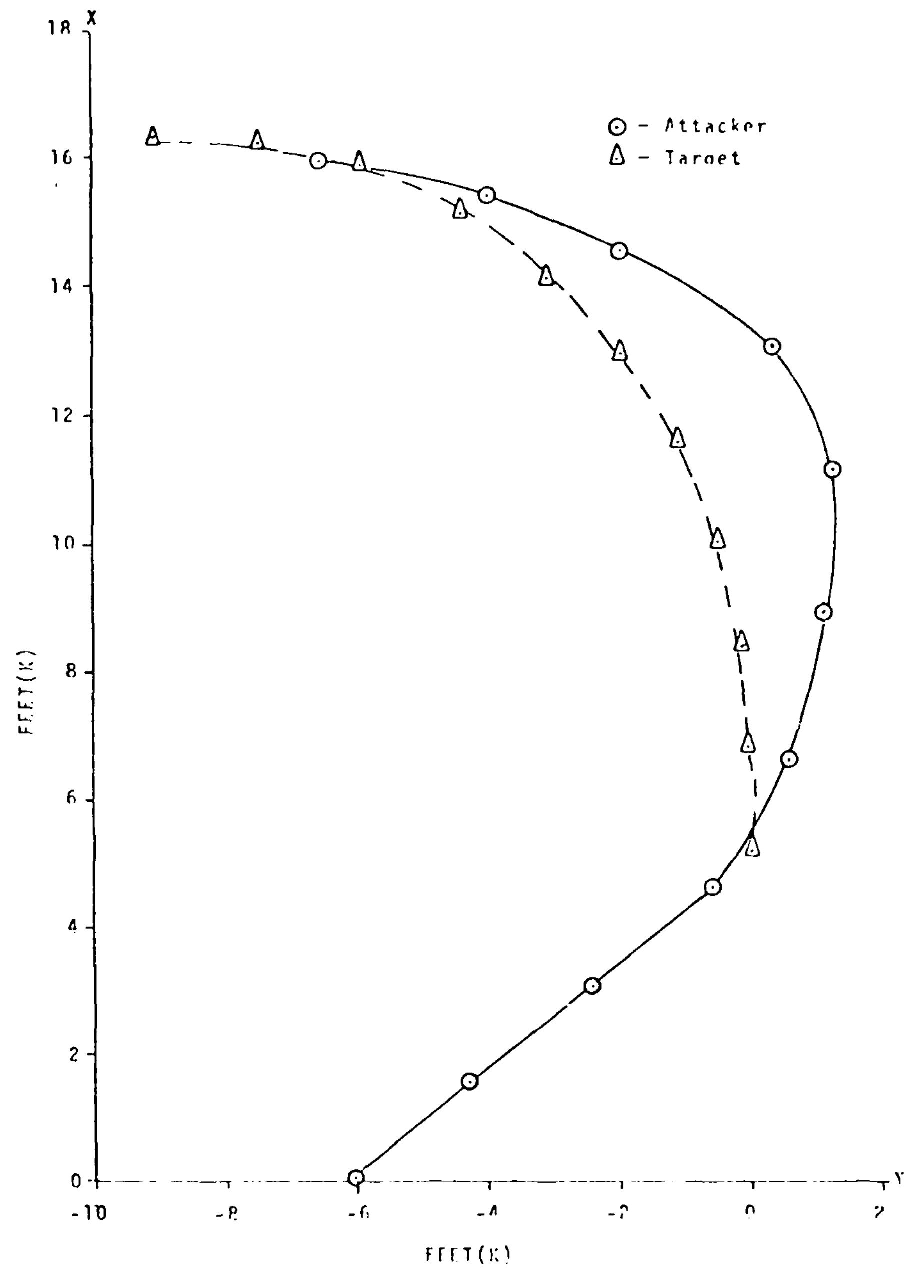

Figure A-1. Original AML against attacker.

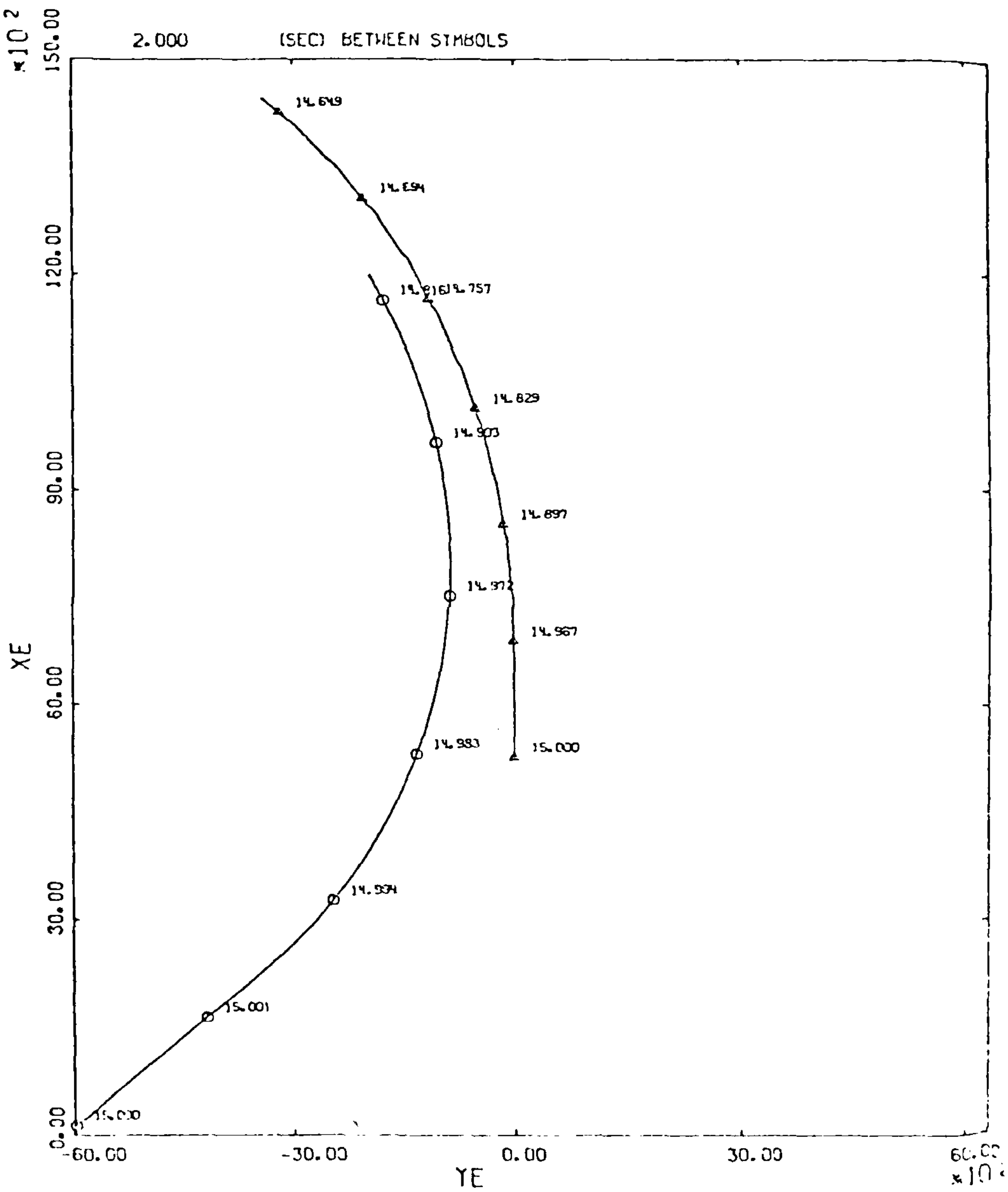

Figure A-2. Original AML against attacker. First decision point error corrected.

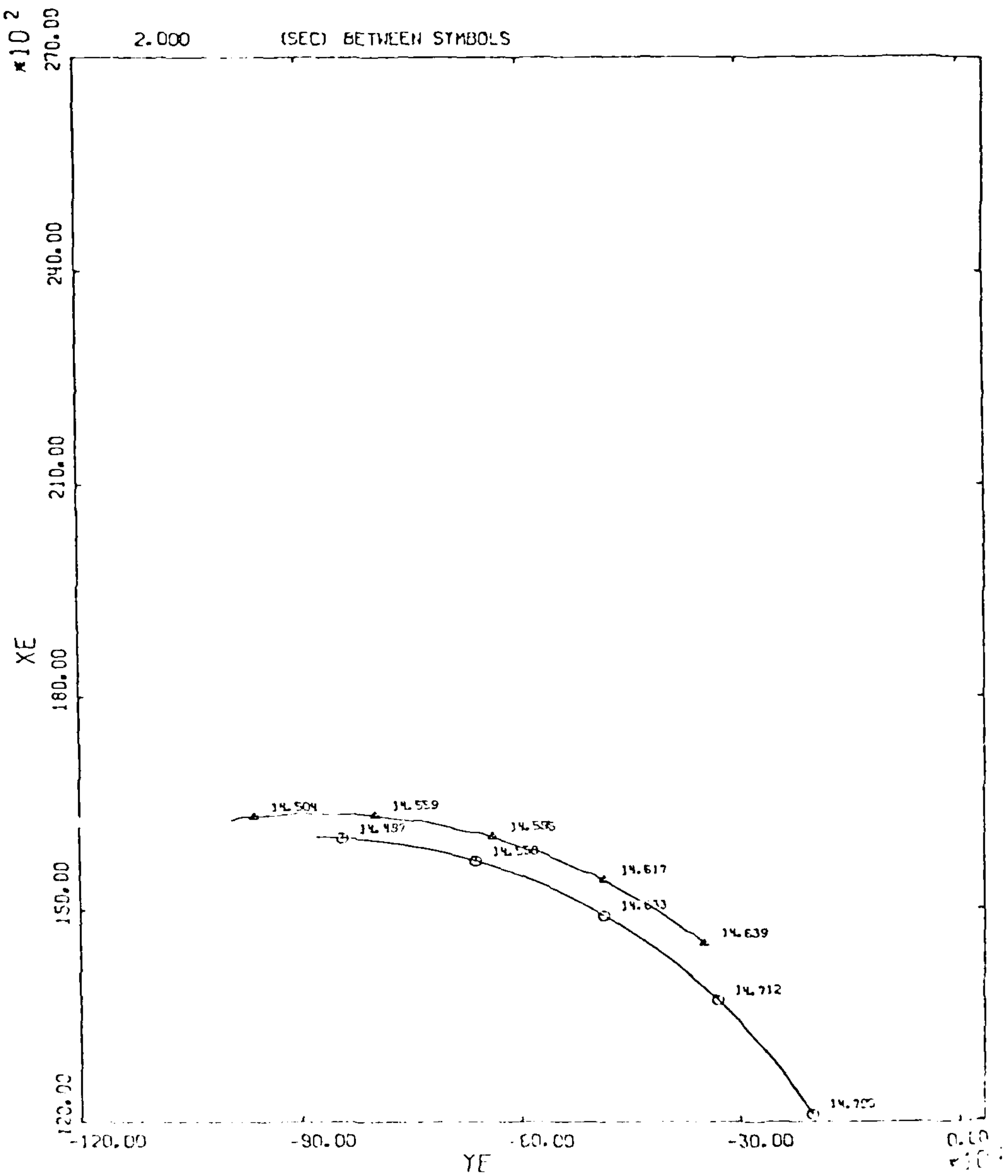

Figure A-2 (Concluded).

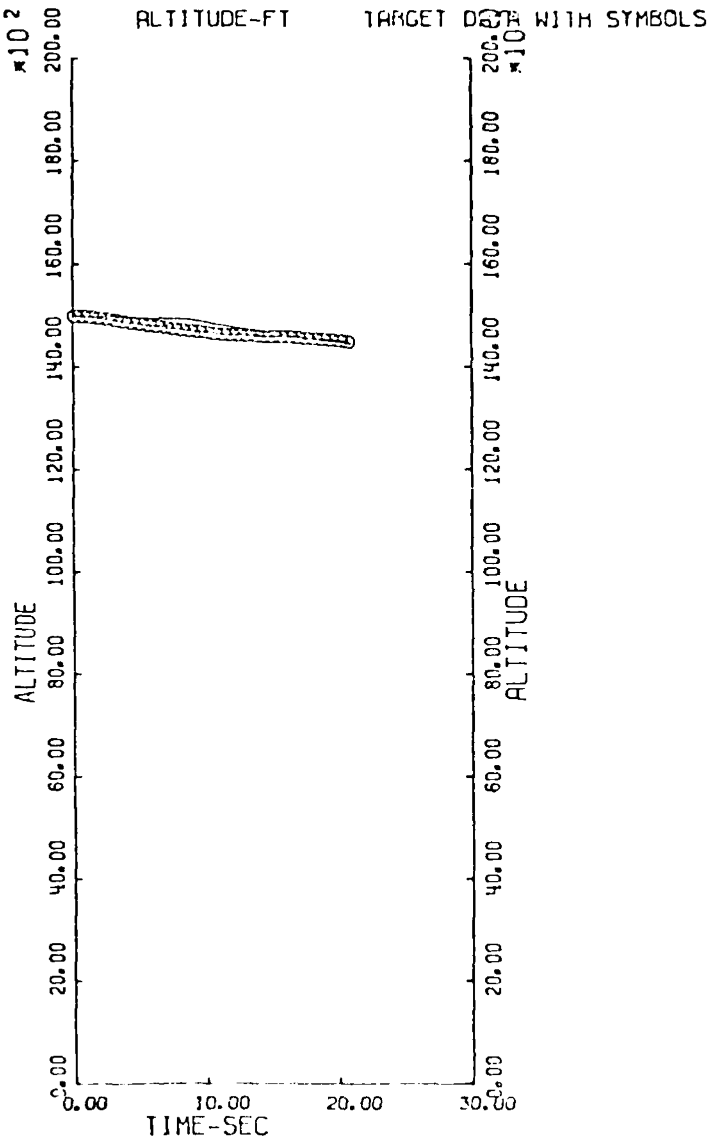

Figure A-3. Altitude plot for Figure A-2.

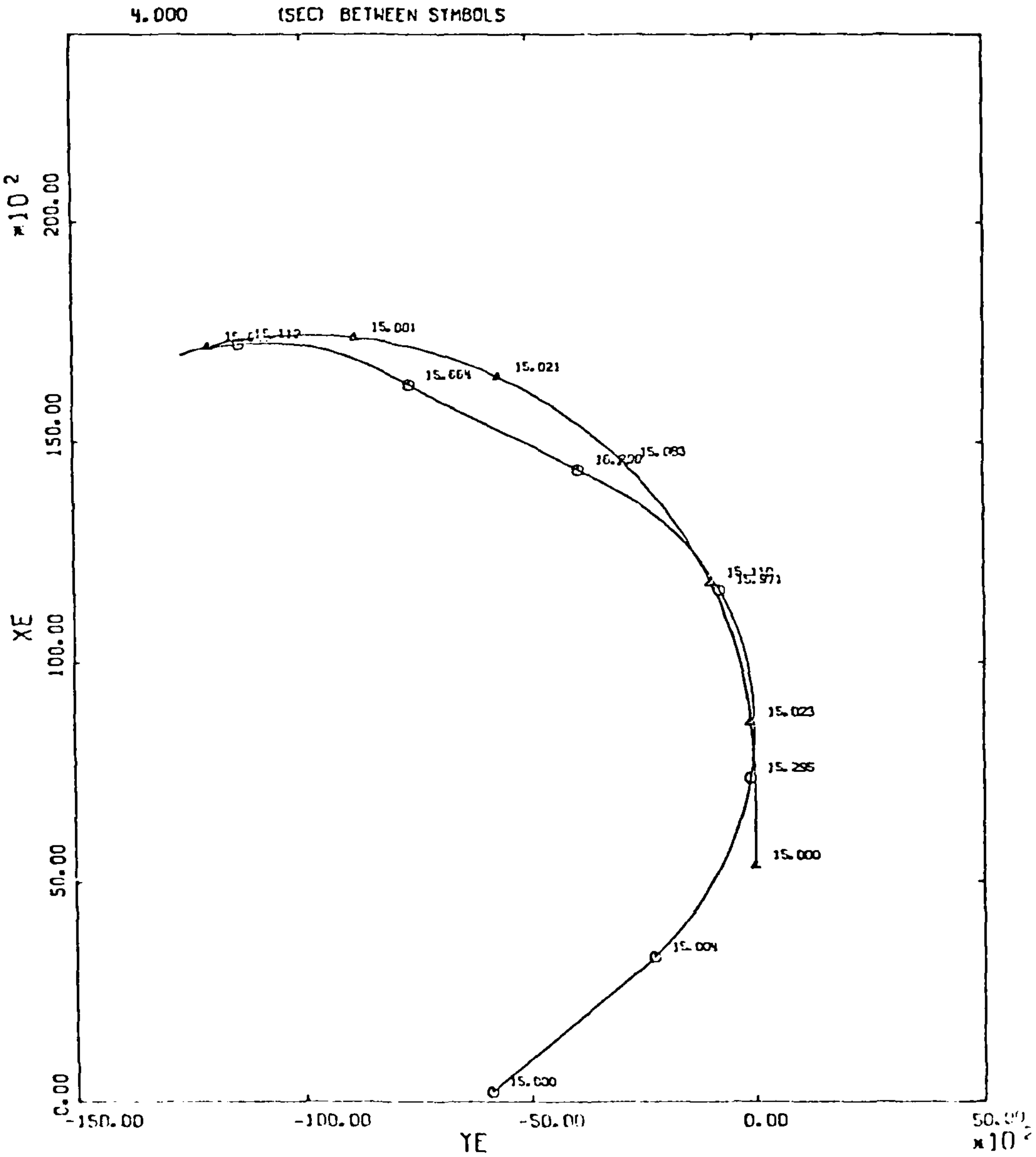

Figure A-4. Ground trace. AML versus LUKE #22.
Weights all 5's.
Tilt angle 15°.

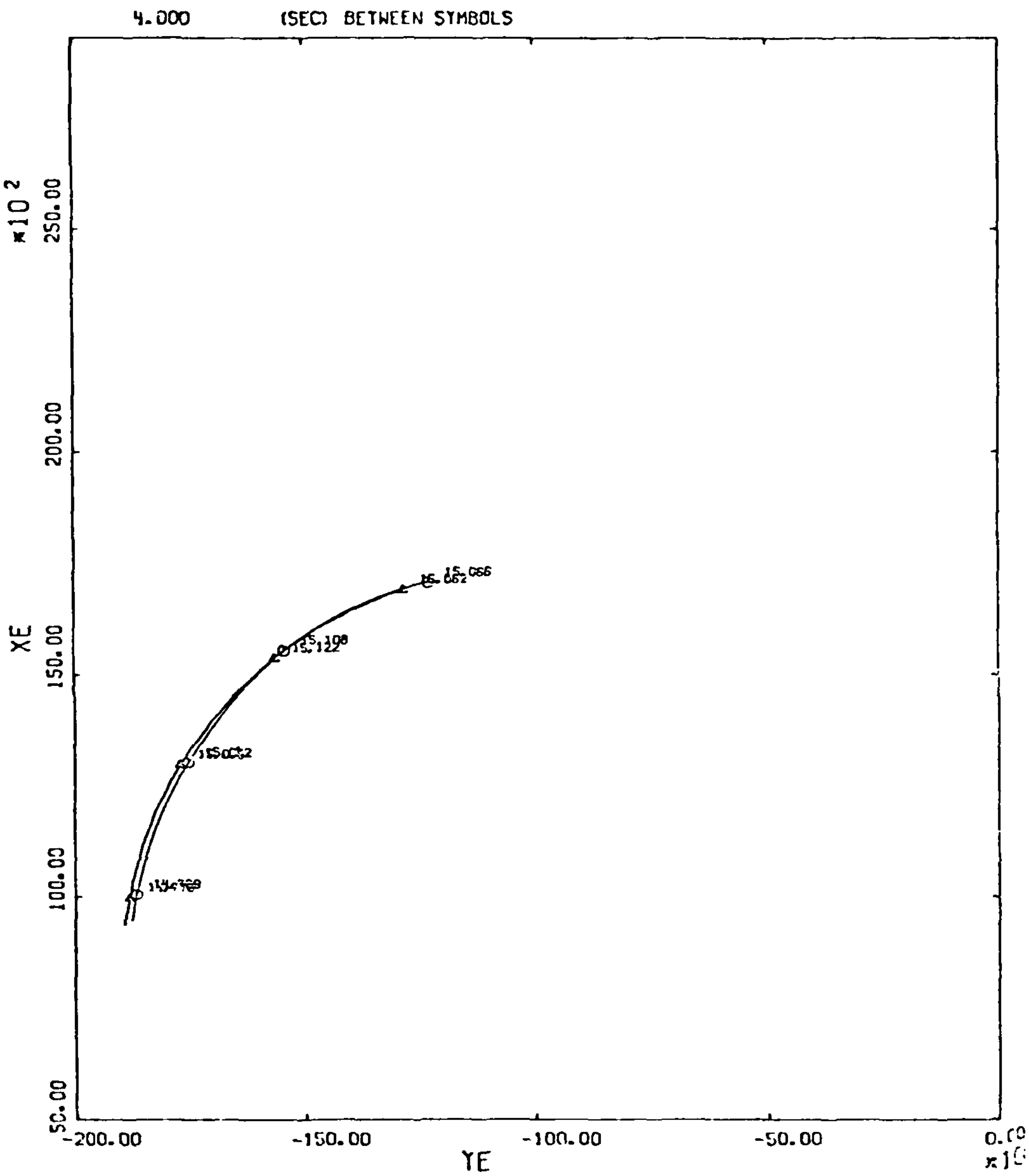

Figure A-4 (Concluded).

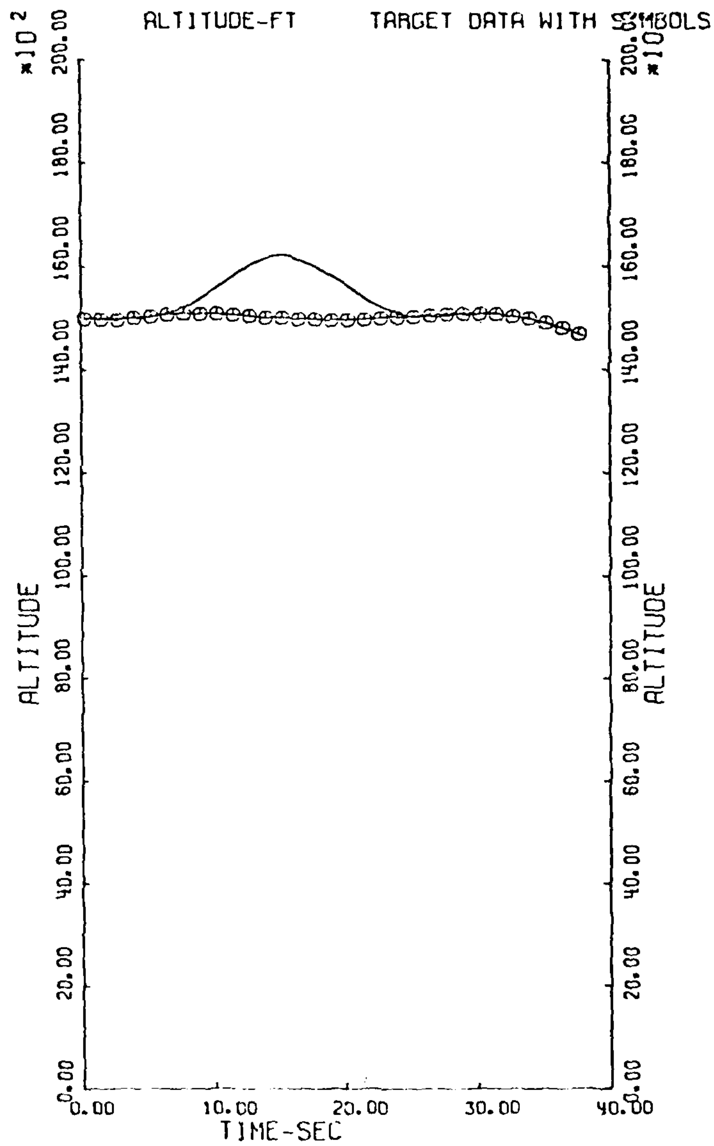

Figure A-5. Altitude plot.
AML versus LUKE #22.
Weights all 5's.
Tilt angle 15°.

angles for the maneuver planes.) Tilt angles of 10 degrees or 15 degrees were used. The weights and tilt angles for each of the five runs are given in Table A-1. Both sets of five runs used the same sets of weights and tilt angles.

Each of the five runs with the same reference run followed the general pattern of the reference run and did not display any distinctive differences among themselves. Each flight did a high-speed yo-yo with the apex occurring at the same time as the reference yo-yo but at a lower altitude. Also, each flight after the apex homed in more quickly on the target and reached the target's altitude sooner than did the reference yo-yo.

Next, a more drastic change was made in the weights. The weights for the first two parameters, altitude and altitude rate, were set to zero; flights were made with both runs #14 and #22 as reference. The results were quite different. The flight with reference run #14 was a high-speed yo-yo with slightly lower apex than previous flights but better ground trace. Plots are given in Figures A-6 and A-7. The flight with reference run #22 was a low-speed yo-yo with a poorer ground trace. Plots are given in Figures A-8 and A-9.

A more careful study of the output data showed that in all trial maneuvers, the velocities were the same at a decision point so that this parameter did no differentiating. An analysis of the program revealed that velocity is not updated during the trial maneuver, so the end velocity for each trial maneuver is the same as at the start. Hence, it is the same for all trial maneuvers; however, the rate of change of the specific energy is updated as is the altitude. The specific energy at the end of the trial maneuver can then be calculated as the specific energy at the start plus the rate of change times the prediction time. Then, since specific energy is equal to the altitude plus the quotient of the velocity divided by 2g, the velocity at the end of the trial maneuver can be completed. This change was incorporated into the program.

TABLE A-1

Weights and Tilt Angle
for the Sets of Five Runs of AML against each Reference Yo-Yo

Parameters	Run 1	Run 2	Run 3	Run 4	Run 5
Altitude	5	1	1	3	3
Altitude Rate	5	5	5	1	1
Velocity	5	3	3	3	3
Load Factor	5	5	5	5	5
Range	5	1	1	1	3
Range Rate	5	5	5	5	1
LOS	5	5	5	5	5
Throttle	5	1	1	1	1
Tilt Angle	10^o	10^o	15^o	15^o	15^o

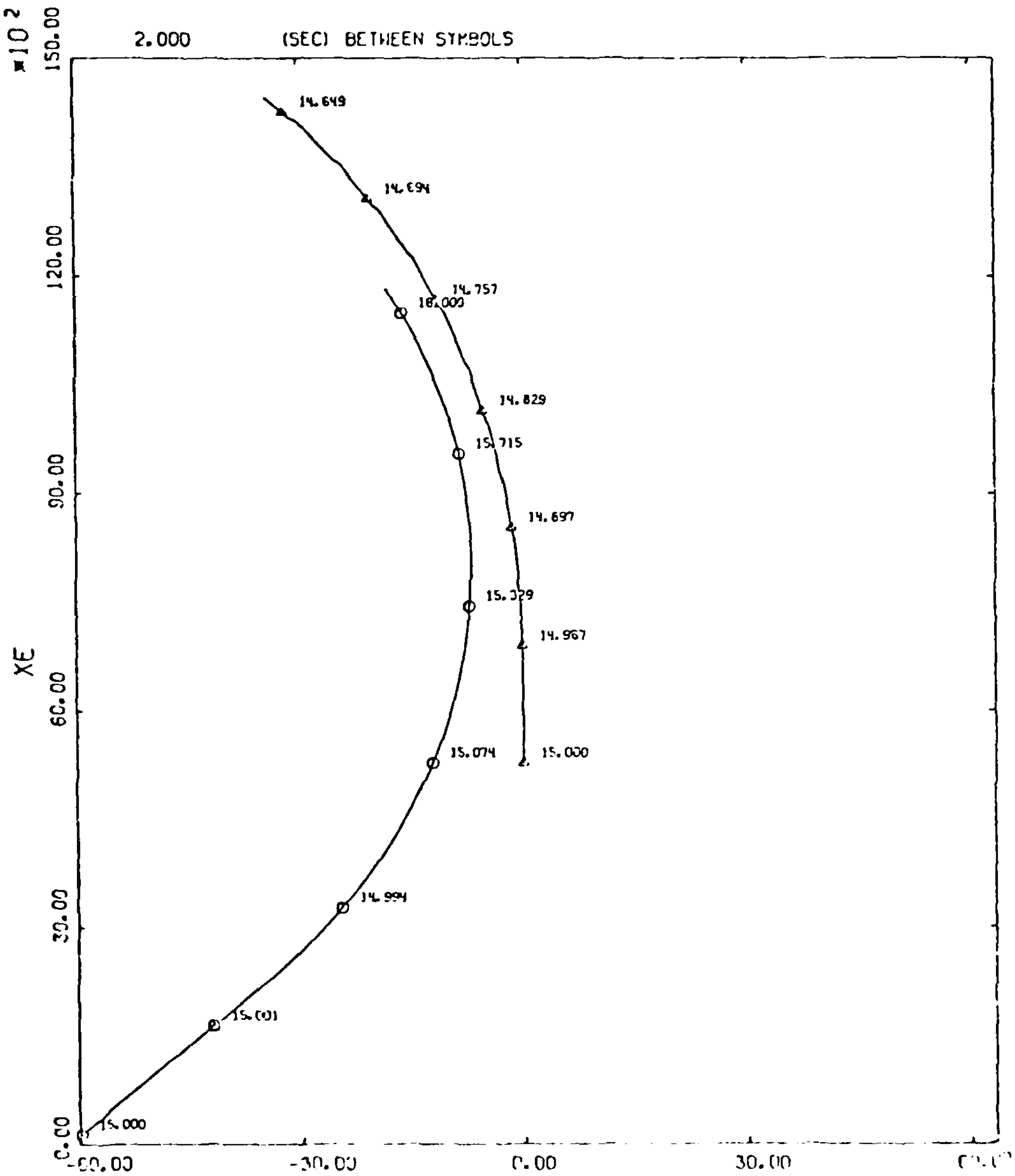

Figure A-6. Ground trace. AML versus LUKE #14.
Weights 0, 0, 3, 5, 3, 1, 5, 1.
Tilt angle 15°.

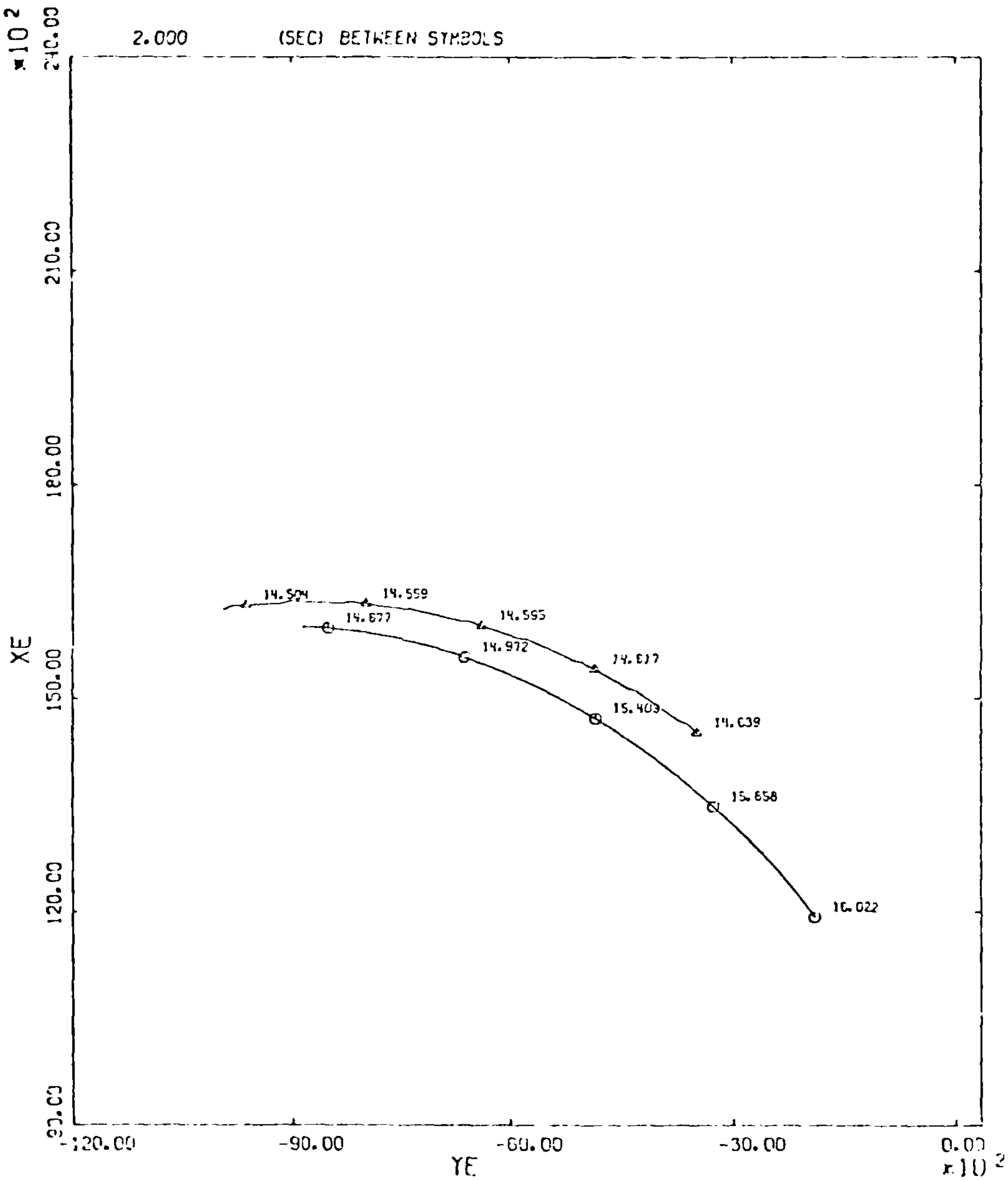

Figure A-6 (Concluded).

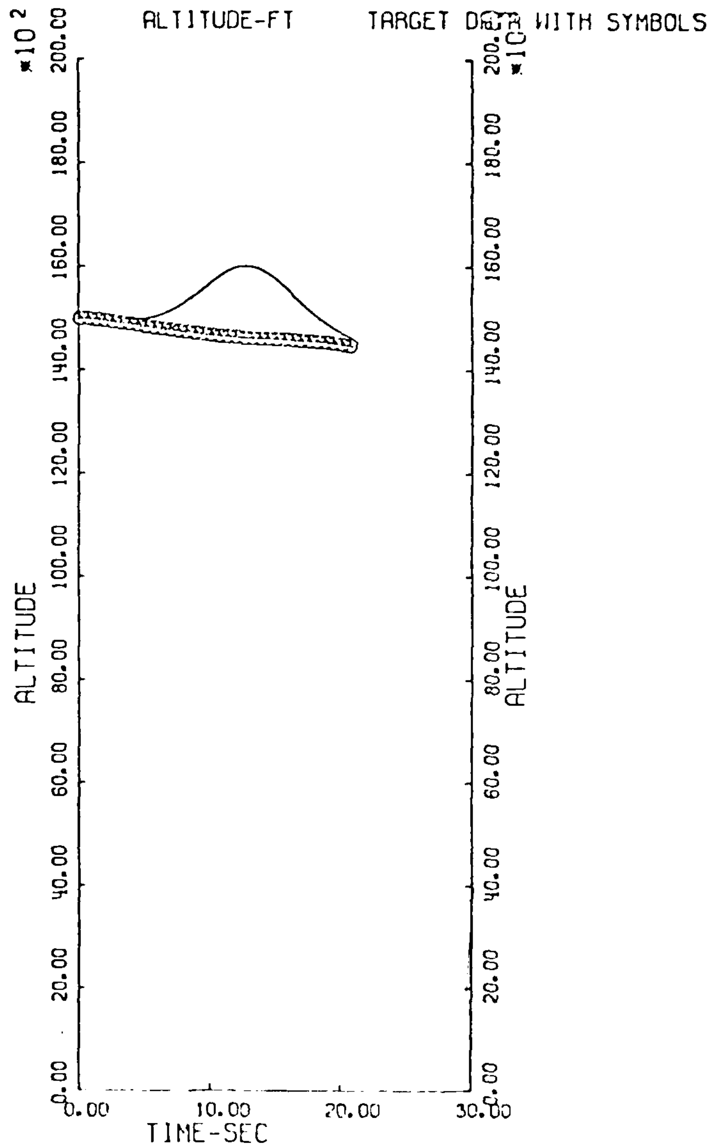

Figure A-7. Altitude plot.
AML versus LUKE #14.
Weights 0, 0, 3, 5, 3, 1, 5, 1.
Tilt angle 15°

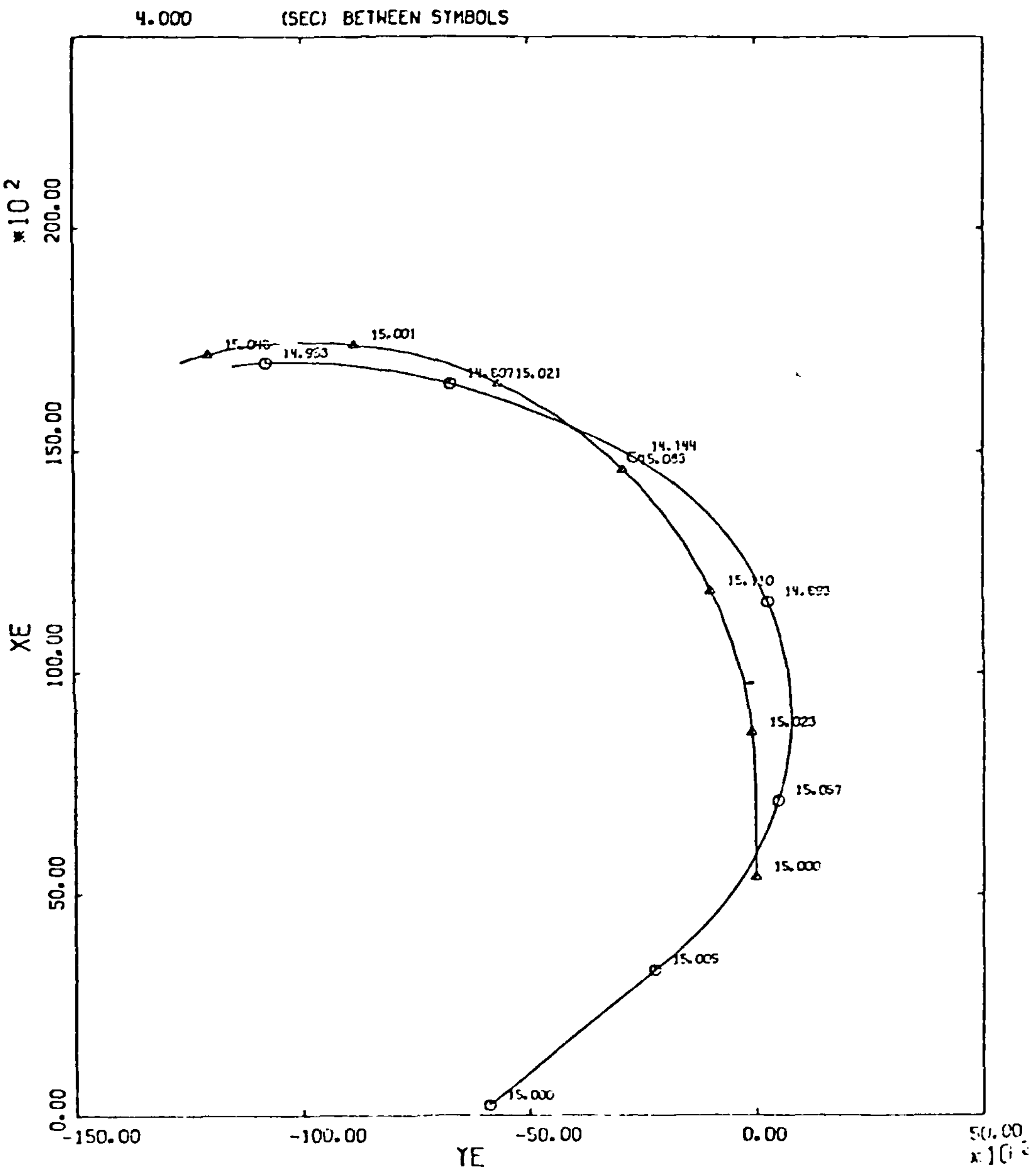

Figure A-8. Ground trace. AML versus LUKE #22.
Weights 0, 0, 3, 5, 3, 1, 5, 1.
Tilt angle 15°.

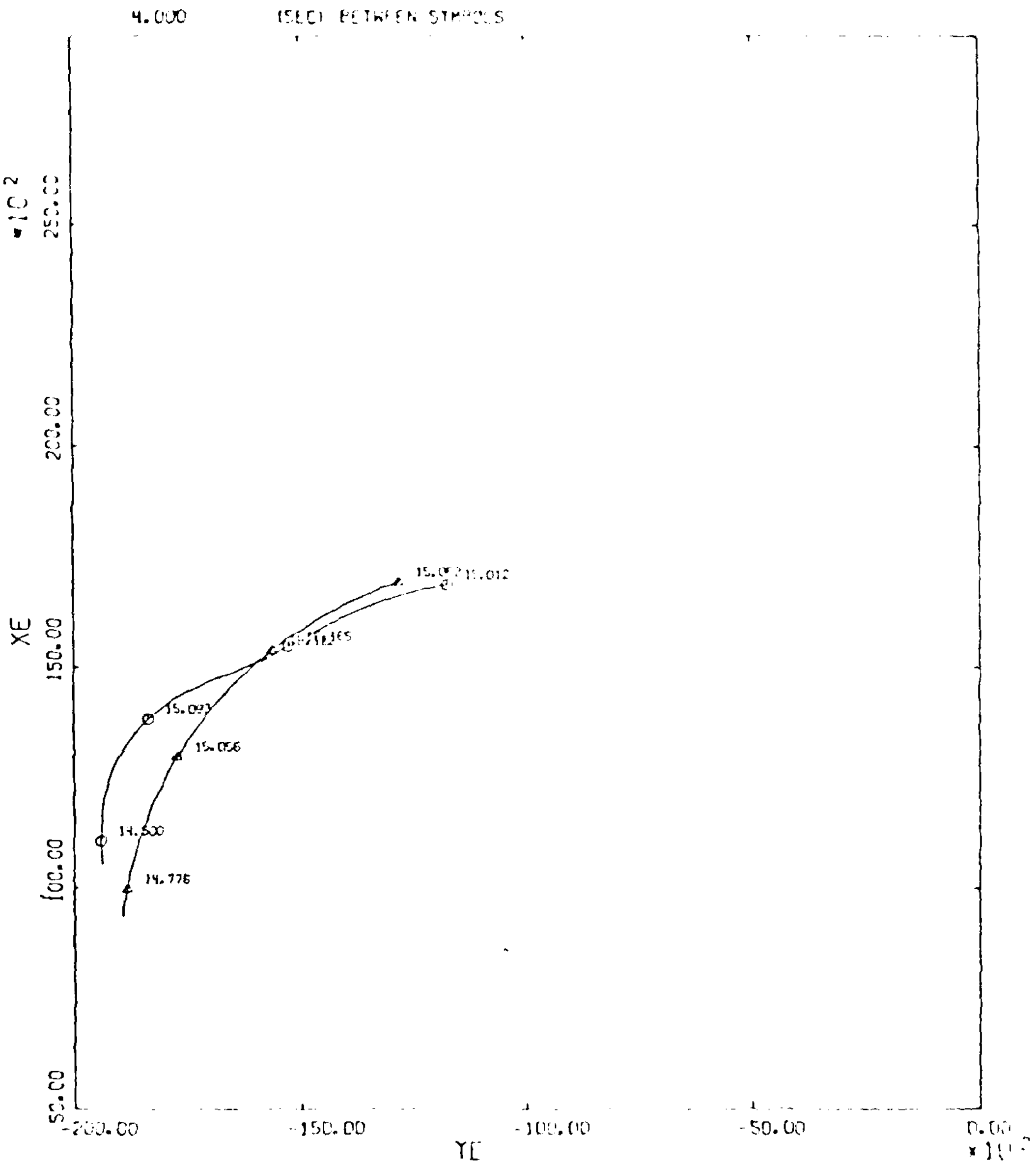

Figure A-8 (Concluded).

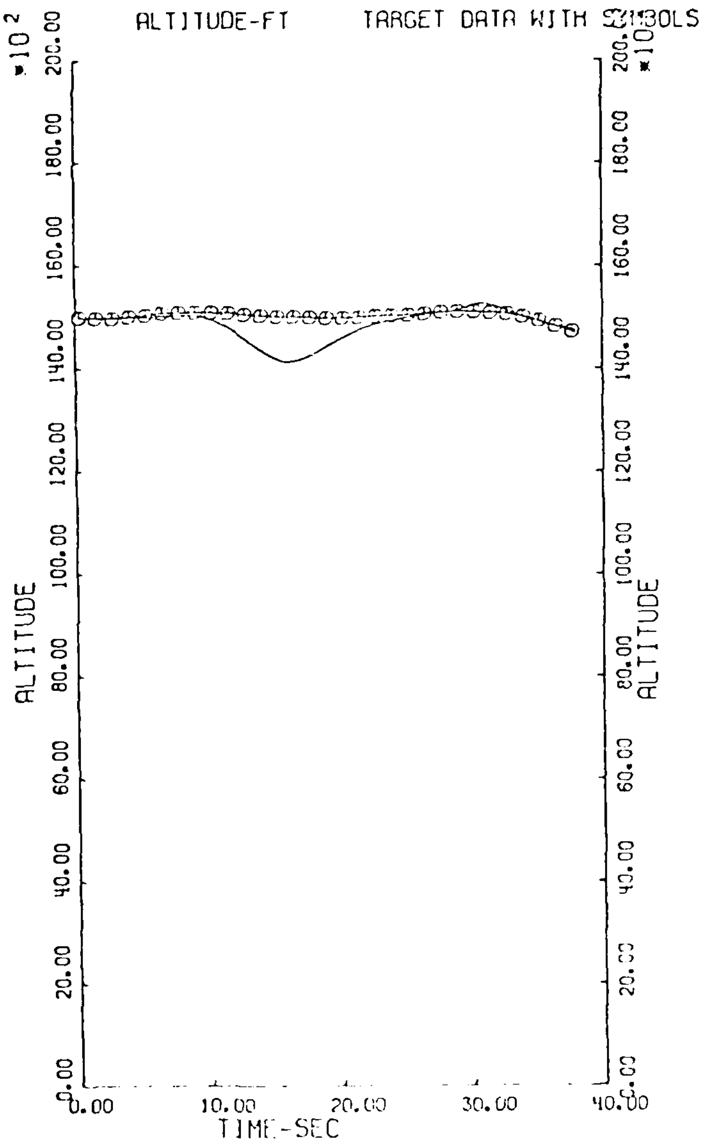

Figure A-9. Altitude plot. AML versus LUKE #22.
Weights 0, 0, 3, 5, 3, 1, 5, 1.
Tilt angle 15°.

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